RECEIVED
MAR 3 1966

FINAL REPORT
ON
THERMAL RESISTANCE MEASUREMENT TECHNIQUES
STUDY PROGRAM

JPL P.O. No. K-382143

Prepared for

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California

This work was performed for the Jet Propulsion Laboratory California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

FROM DIODES TO INTEGRATED CIRCUITS . . .

ADVANCED TECHNOLOGY THROUGH MOTOROLA RESEARCH

MOTOROLA INC. Semiconductor Products Division

TABLE OF CONTENTS

RE-ORDER NO. 66-74

FINAL REPORT
ON
THERMAL RESISTANCE MEASUREMENT TECHNIQUES
STUDY PROGRAM

JPL P.O. No. K-382143

Prepared for
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
4800 OAK GROVE DRIVE
PASADENA, CALIFORNIA

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, pursuant to a sub-contract issued under Prime Contract NAS7-100 between the California Institute of Technology and the United States of America represented by the National Aeronautics and Space Administration.

by
Paul H. Greer
Kenneth W. Davidson

MOTOROLA INC.
SEMICONDUCTOR PRODUCTS DIVISION
5005 EAST MCDOWELL ROAD
PHOENIX, ARIZONA

11 February 1966

TABLE OF CONTENTS (Cont'd.)

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (Cont'd.)

1.0 INTRODUCTION

This contract was initially conceived as a result of discussions with Mr. Larry Wright of the Jet Propulsion Laboratory (JPL), concerning the critical need for accurate thermal resistance measurements on transistors.

Since JPL test programs and experiments currently in the planning stages are to be run with semiconductors operated in ovens at 100°C, an accurate method of measurement of θJ-C and θC-A to determine actual operating junction temperatures of the devices will be required.

This report describes a three-month program performed by Motorola Semiconductor Products Division whereby a thermal resistance measuring technique was refined and its accuracy and repeatability determined.

Figure 1 shows the overall Program Test Plan and the quantity of units used for the various tasks.

The Motorola type 2N2222 silicon annular epitaxial NPN transistor was selected as the test vehicle for this program since this is to be the device evaluated in a proposed large-scale accelerated test program for JPL. A Motorola data sheet for the 2N2222 is included in the Appendix (Section 8.0) of this report.

A total of 355 devices were tested on this program, all from Motorola production lot 544, process SL3-05, manufactured the week of 11-5-65.

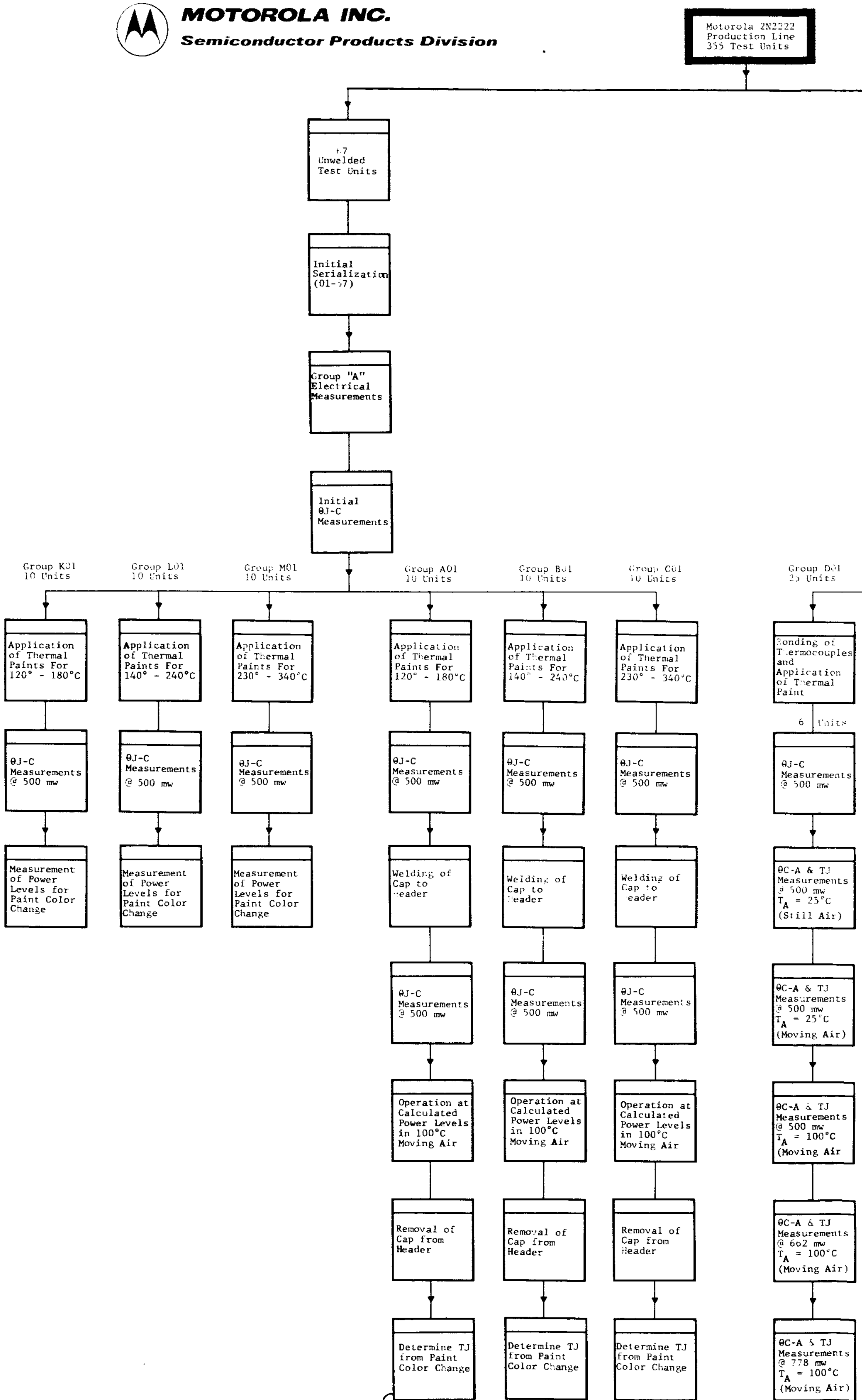
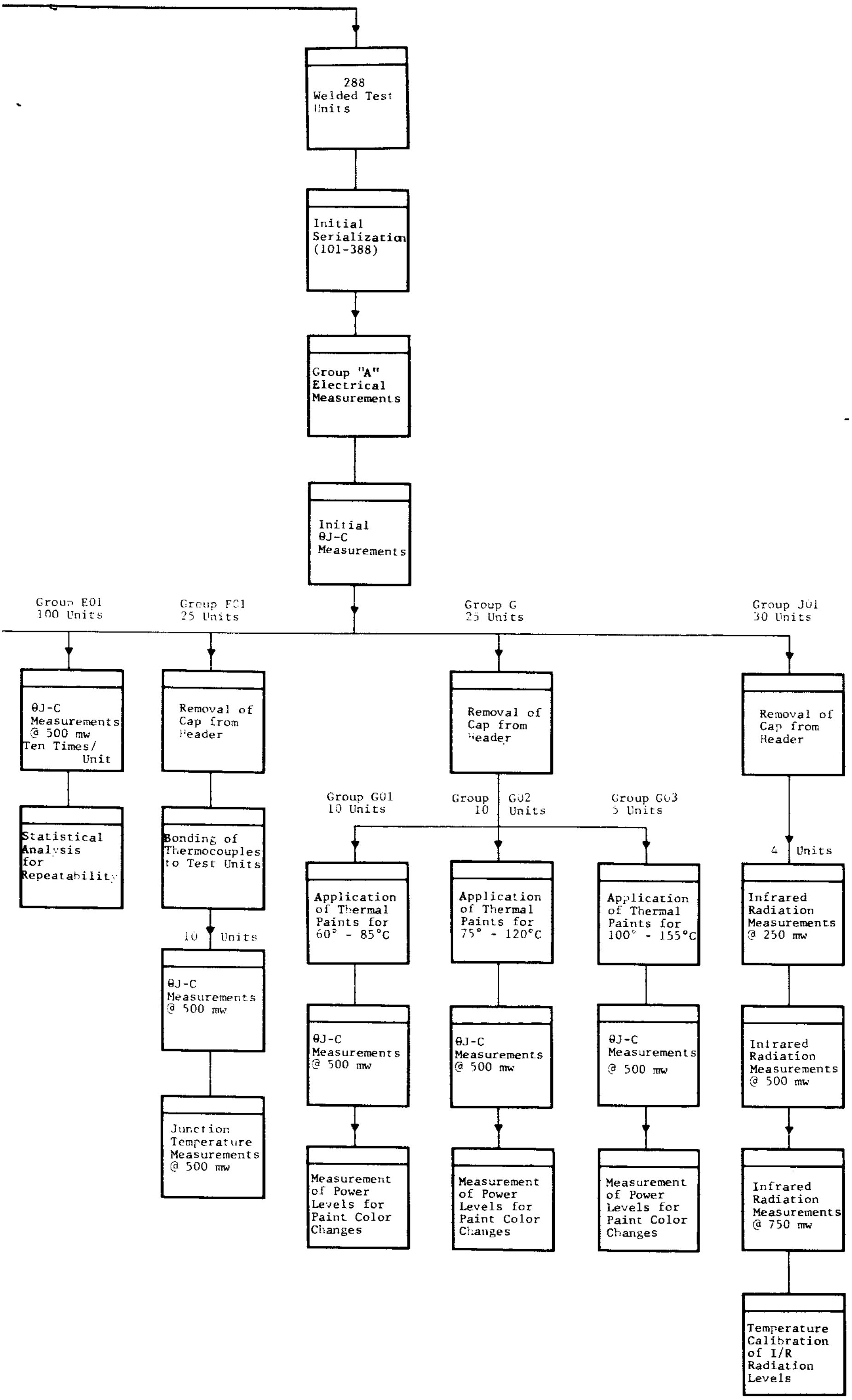


Figure 1. Program T


288 Welded Test Units
Initial Serialization (101-388)
Group "A" Electrical Measurements
Initial θJ-C Measurements
Group E01 100 Units
Group FC1 25 Units
Group G 25 Units
Group J01 30 Units
θJ-C Measurements @ 500 mw Ten Times/ Unit
Statistical Analysis for Repeatability
Removal of Cap from Header
Bonding of Thermocouples to Test Units
10 Units
θJ-C Measurements @ 500 mw
Junction Temperature Measurements @ 500 mw
Removal of Cap from Header
Group G01 10 Units
Group 10
G02 Units
Group G03 5 Units
Application of Thermal Paints for 60° - 85°C
Application of Thermal Paints for 75° - 120°C
Application of Thermal Paints for 100° - 155°C
θJ-C Measurements @ 500 mw
θJ-C Measurements @ 500 mw
θJ-C Measurements @ 500 mw
Measurement of Power Levels for Paint Color Changes
Measurement of Power Levels for Paint Color Changes
Measurement of Power Levels for Paint Color Changes
Removal of Cap from Header
4 Units
Infrared Radiation Measurements @ 250 mw
Infrared Radiation Measurements @ 500 mw
Infrared Radiation Measurements @ 750 mw
Temperature Calibration of I/R Radiation Levels

2.0 OBJECTIVES

The primary objectives of this contract were:

2.1 Phase I Tests - Measurement Methods for θJ-C

To refine the present method of measuring θJ-C of individual 2N2222 transistors and determine if its absolute accuracy was ±10% with a repeatability of ±5% or better.

2.2 Phase II Tests - θJ-C Measurement Accuracy and Repeatability

To verify the accuracy and repeatability of the θJ-C measurement method by one or more independent measurement techniques.

2.3 Phase III Tests - Measurement of θJ-A

To develop a method of accurately determining θJ-A for the 2N2222 device (TO-18 package) in the 100°C forced draft air flow ambient conditions to be used in the accelerated test program.

3.0 PHASE I TESTS - MEASUREMENT METHOD FOR θJ-C

Upon receipt of the contract, Phase I tests were initiated to determine if the existing Motorola Quality Control thermal resistance tester (referred to herein as tester HO-01) was suitable for use on Phase II and III tests or would require modification or a replacement tester. The following sections present the details of these tests with significant results.

3.1 Initial Correlation Studies

At the commencement of this program, the Motorola SL3-05 production line from which the 2N2222 test units were to be obtained was just starting production following completion of a scheduled shutdown dating back to August, 1965. Rather than delay the program by waiting until the first new production lot was to be available (lot 544 - to be welded the week of 5 November, 1965), a sample of 25 devices from lot 531 (welded week of 6 August, 1965) were obtained from the warehouse for use as initial correlation samples.

Initial θJ-C measurements were made on 21 of the 25 samples on tester HO-01 at three power levels, 250mW, 500mW, and 750mW (See Table 3.1). The mean values obtained were 152°C/W at 250mW, 89.5°C/W at 500mW, and 83.4°C/W at 750mW. The specification limit on θJ-C for the 2N2222 is only 83.3°C/W and should not be dependent upon power level (within the range of values in question), therefore, the accuracy of the measurements was questionable.

Accordingly, a review of the principles of operation of thermal resistance tester HO-01 was undertaken.

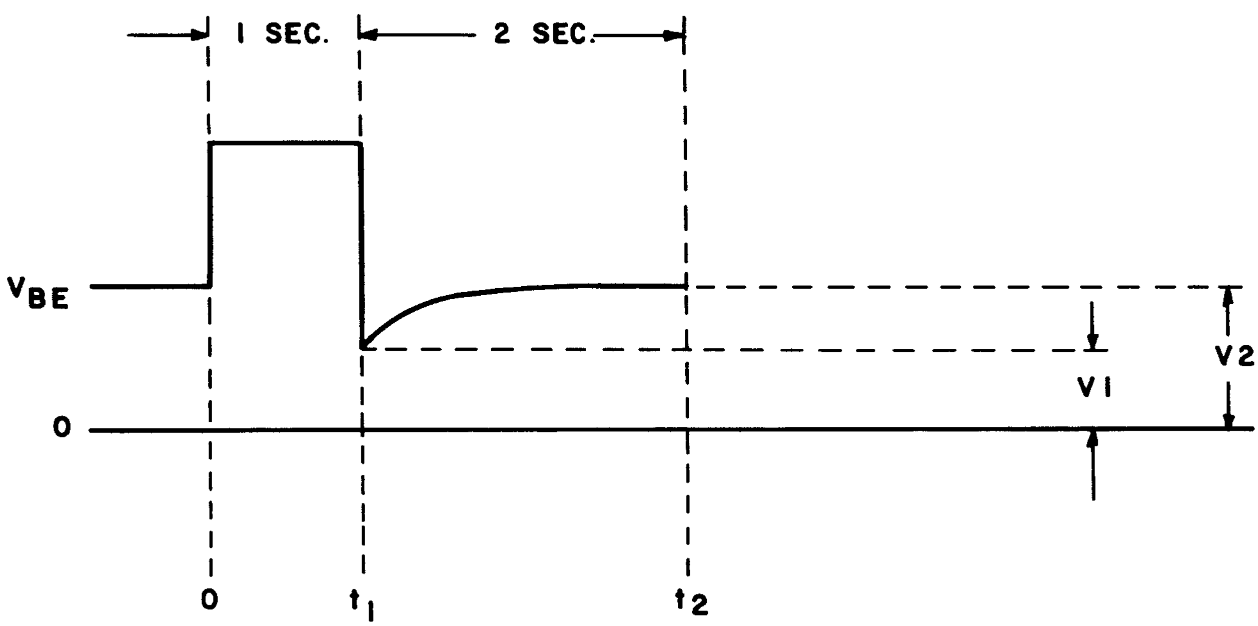
The thermal resistance of a transistor is defined as the effective temperature rise per unit of power dissipated in a designated junction above the temperature of a stated reference point under conditions of steady-state operation. In this particular program, the junction designated for power dissipation was the collector-base junction and the reference point was the transistor case. This can be stated mathematically as follows:

$$\theta J\text{-}C = \frac{TJ - TC}{P} \qquad (1)$$

where TJ = Junction Temperature
TC = Case Temperature
P = Power Dissipation in collector-base junction
θJ-C = Thermal Resistance

In equation (1), the case temperature TC and the power dissipation P could readily be measured by direct methods; however, the junction temperature TJ would have to be measured indirectly using a temperature-sensitive electrical parameter of the transistor. We chose to use the temperature characteristic of VBE, which is the forward drop of the emitter-base diode. The test cycle, shown in Figure 2, consisted of applying constant power P for an interval of time t_1 until the temperature difference between case and junction was essentially constant. When the power was removed, a constant low forward bias current was automatically established through the emitter-base diode. The VBE recovery was then sampled at two points; (1) immediately after power was removed, t_1, and (2) after a two-second time interval, t_2.

WAVEFORM OF POWER PULSE AND VBE MEASUREMENT TIMES



4262-10-5

Figure 2

The first sample of VBE represented the maximum junction temperature at the end of the power pulse. The second sample was a measure of VBE with the case and junction assumed to be back to the original equilibrium temperature.

This test method assumed three things: (1) that the thermal capacitance of the case was much greater than that of the emitter-base junction (essentially the die of semiconductor material), thus, the heat stored in the die at the end of the power pulse, when shared with the large thermal capacitance of the case, resulted in a negligible change in case temperature, (2) that the thermal time constant of the case-to-ambient was much larger than the thermal time constant of the junction-to-case and, therefore, the junction temperature reached case temperature within the two-second interval between t_1 and t_2, and (3) that the volume of ambient air surrounding the unit under test was sufficiently large to prevent any significant change in the case-to-ambient value.

The junction-to-case thermal resistance, θJ-C, in °C/watt, was calculated as follows:

$$\theta J\text{-}C = \frac{V1 - V2}{K \times P} \tag{2}$$

where V1 = Value of VBE at T_1, in millivolts

V2 = Value of VBE at t_2, in millivolts

K = Temperature characteristic of VBE in millivolts/°C for silicon devices)

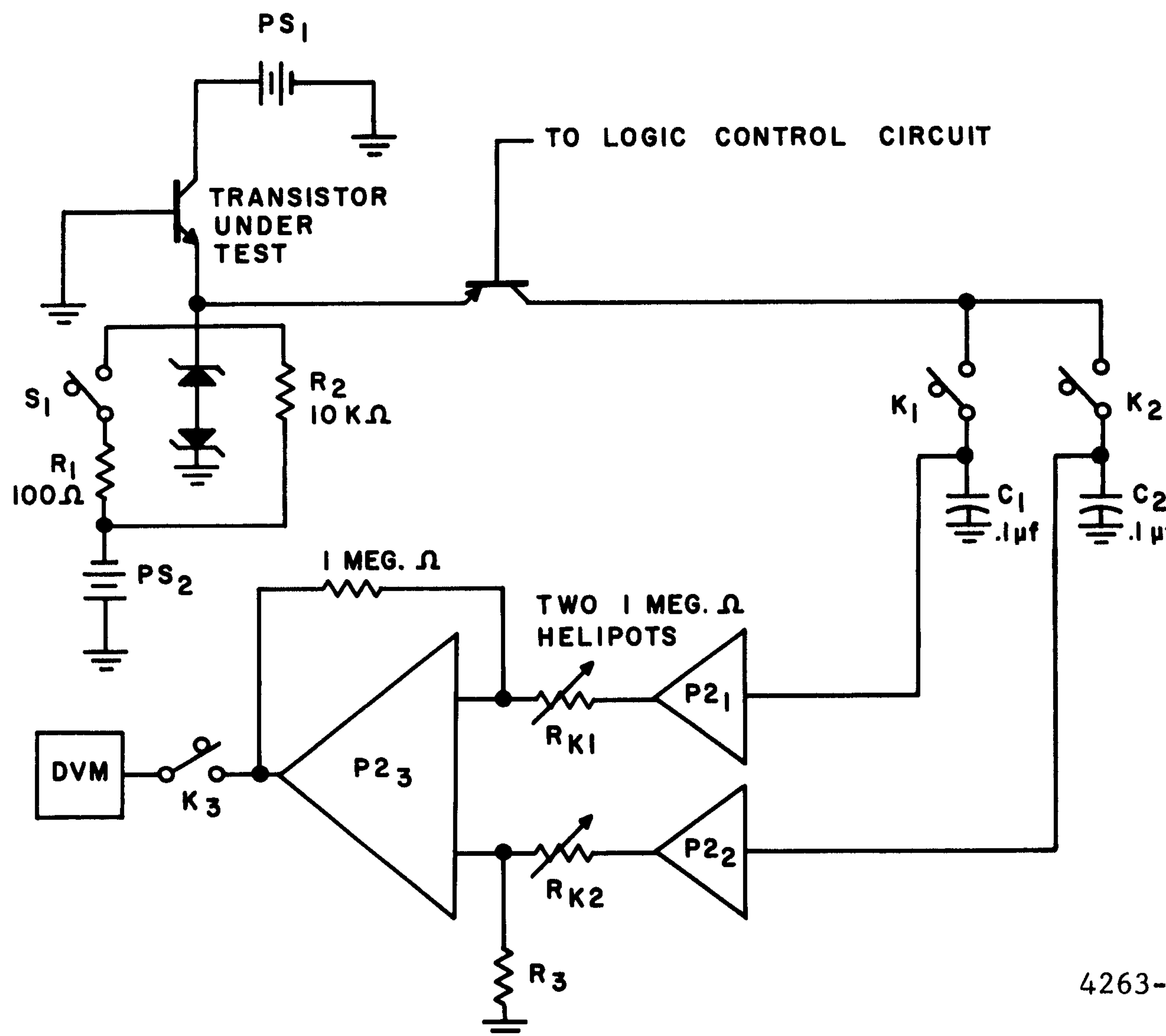
P = Power dissipation in watts

VBE was measured with the same low forward bias current (referred to as sense current) at both sample times, t_1 and t_2. Experimentation at Motorola has shown that the distribution of the thermal characteristic of VBE (at I = 2.0mA, TA = 25°C - 300°C) is very tight with maximum and minimum values remaining within ±3.5% of the mean value for a particular temperature. Thus, once this mean value was determined for the Motorola 2N2222, it was used as a constant in equation (2). Values of sense current as low as 100µA were investigated, but at this current level, the variation between devices was greater due to operating on a non-linear region of the forward characteristic.

A block diagram of the basic test circuit employed is shown in Figure 3. A grounded base configuration is used and since VBE is the critical voltage to be measured, it permits ground to be used as a convenient reference point for performing measurements. By use of logic circuitry, the value of VBE at time t_1 (V1) is stored in capacitor C1 and the value of VBE at time t_2 (V2) is stored at capacitor C2. These two values of VBE are amplified by a difference operational amplifier to provide an accurate value of V1 - V2 for equation (2). By additional logic circuitry and use of decade levels of power dissipation, the measurement system was easily modified to give direct θJ-C readout in °C/watt on the digital voltmeter.

Careful study of the three assumptions made revealed that the second and third assumptions were valid, but there was a possibility that the first one was not valid. Measurements were made of case temperature on a device during θJ-C measurements on tester HO-01 at 250mW, 500mW, and 750mW (See Table 3.1).

BASIC θ_{J-C} MEASUREMENT TEST CIRCUIT



4263-10-5

Figure 3

Case temperature rises of 2.0°C, 5.0°C, and 6.5°C respectively were observed. The effect of this case temperature change on θJ-C accuracy was evaluated by testing seven correlation sample devices ten times each on tester HO-01 in the normal manner and then repeating the measurements with the cases of the same test devices immersed in circulating deionized water at room ambient temperature (See Table 3.3). The results of this study showed no significant difference between θJ-C values measured in free air and in the water bath. Further study showed that for a TO-18 case in free air, a 1-second 500mW power pulse would indeed raise the case temperature approximately 5°C, but during the two seconds following the power pulse, this 5°C change would only decrease by 0.5°C. Since the two samples of VBE are taken during the two seconds following removal of power, the 0.5°C decrease in case temperature would have negligible effect.

Since these investigations did not give a definite answer for the high θJ-C values and variations among power levels, another Motorola thermal resistance tester (referred to herein as the bench tester) was evaluated. The bench tester was originally the main θJ-C tester used by Quality Control, but it has been replaced by HO-01 because of its slow test rate. However, it has been kept in part-time use as a calibration standard for HO-01.

The bench tester employs a 90% duty cycle square wave to apply power and sense conditions to the device under test. Power is on for approximately 40 milliseconds and then removed for 4 milliseconds while a 2mA sense current is used to measure VBE. By using an oscilloscope as the readout device, the value of VBE at 2mA sense current and power off condition is set to zero on the scope by a nulling voltage potentiometer. When the power switch is turned on, a phase control is used to adjust two timing relays so that the VBE value can be viewed almost immediately after the 40 millisecond power on condition ends. Since the average power dissipation is 90% of its steady state value with this system, the device under test is immersed in circulating deionized water during θJ-C measurements. By operating the device in free air, the same tester is used for θJ-A measurements.

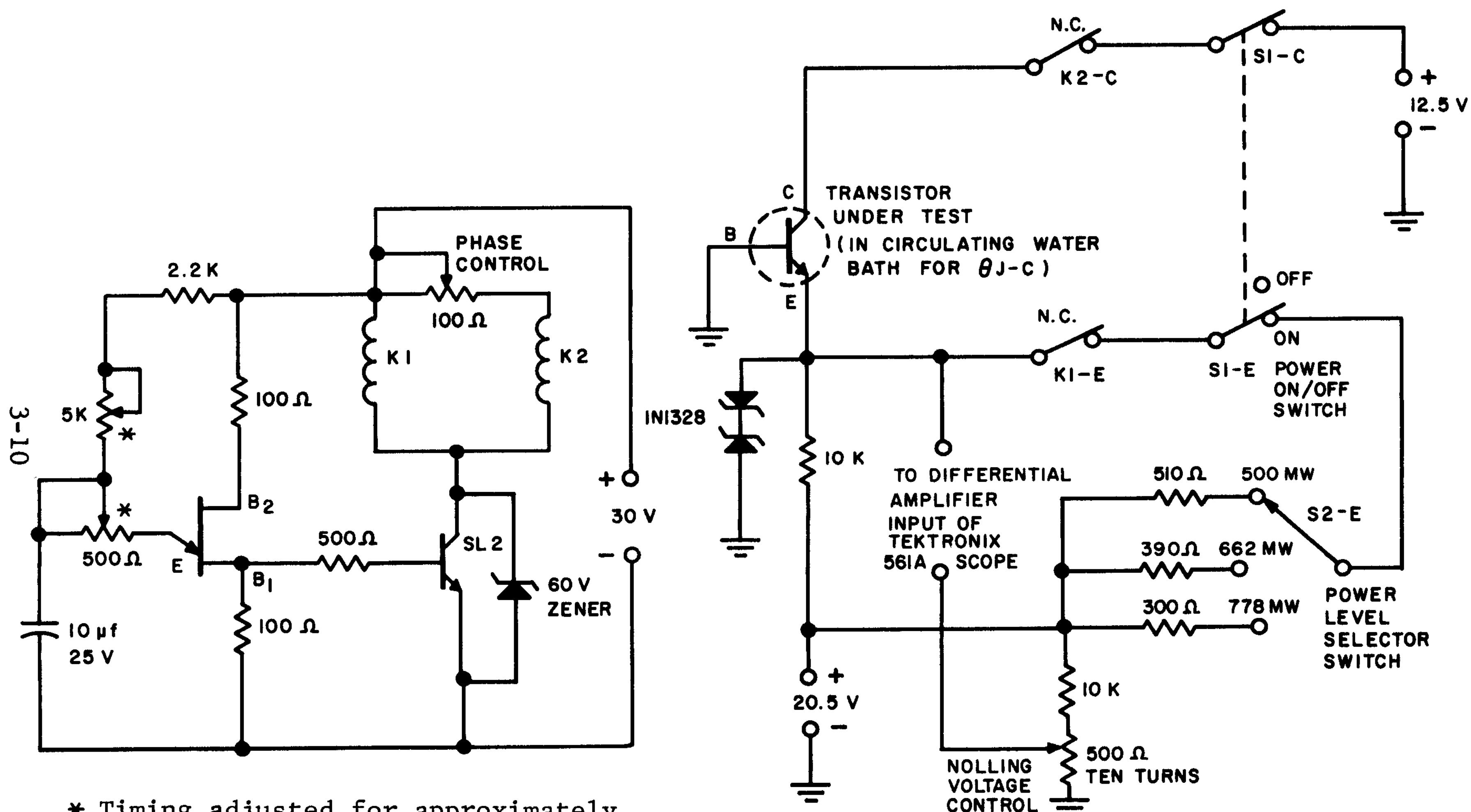
Another set of θJ-C data was obtained on the 25 correlation samples using the bench tester (See Table 3.1). For power levels of 250mW, 500mW, and 750mW, the mean values of θJ-C obtained were 93.6°C/W, 97.8°C/W, and 103.6°C/W respectively. At 500mW, this represented a mean value of 17% above the maximum specification limit of 83.3°C/W. However, the variation with power levels was only about ±5% (500mW nominal). To evaluate the repeatability of the bench tester, a group of six devices from the correlation samples were retested at the same three power levels (See Table 3.2). The repeatability was found to be within ±5% at all three power levels.

A study of the oscilloscope waveforms obtained from the bench tester indicated that the entire leading edge of the exponential decay of VBE following removal of power was missing. Circuit analysis revealed that a set of relay contacts on the sensing relay were being used to connect the VBE output to the oscilloscope terminals. The delay caused by this relay was responsible for missing part of the exponential waveform.

The contacts on the sensing relay connecting the scope to the VBE viewing circuit were disconnected and the emitter voltage brought out directly to a differential amplifier input to the scope. The nulling voltage was brought out to the other side of the differential amplifier to permit a zero voltage adjustment prior to applying power. The circuit of the bench tester after these modifications were completed is shown in Figure 4.

The six correlation samples previously tested on the bench tester for repeatability were tested again at 500mW to observe the effect of removing the sensing relay contacts from the circuit (See Table 3.2). The effect observed was an additional 5.9% increase in the mean value of θJ-C.

Since the change to the bench tester and the subsequent modification of the sensing relay circuit resulted in θJ-C values even higher than the maximum 2N2222 specification limit, it was decided to use tester HO-01 for the initial θJ-C measurements on the 355 contract test units (from lot 544). In setting tester HO-01 back up for testing the test devices, it was observed that the 2mA sense current continued to flow during the 1-second power pulse in addition to the programmed 40mA even though the panel indicator on the tester indicated that IC was only 40mA. This meant that the data taken previously (Table 3.1) was in error because the power levels were actually 275mW, 525mW, and 770mW, rather than the 250mW, 500mW, and 750mW desired. This error was corrected and the correct power levels were used for the initial thermal impedance data on the contract test devices (See Section 3.3).



* Timing adjusted for approximately 90% duty cycle - Power on 42 ms, Power off 3.8 ms

Figure 4. Thermal Resistance Test Set - Calibration Standard

4735-2-6

Since there was considerable test data to support the results obtained on the bench tester, even though the mean values were 23% above the specification limit, an additional test to verify the data was performed. One unit from the original 25 correlation units and one unit from the contract test devices were measured on the bench tester for θJ-C with the sensing relay contacts disconnected and then with the contacts connected (See Table 3.4). Instead of using the circulating deionized water bath, however, the case of the device under test was mounted on a thermoelectric cooler/heater with an adapter to fit the TO-18 case. After the ΔVBE had been measured at 500mW, the power was removed and the case of the transistor raised in temperature with the thermoelectric cooler/heater until precisely the same ΔVBE was observed. For one device (S/N 115), the 500mW produced a ΔVBE of 102mW (sense relay in). With the previously assumed VBE temperature coefficient ("K" factor) of -2.0mV/°C for silicon devices, the 102mV change in VBE represented a 51° change in junction temperature (TJ). However, it required a temperature difference of 55.5°C from the thermoelectric cooler to achieve the 102mV change in TJ. Similar results were obtained with the second unit (S/N 3). The lack of correlation between these two methods indicated the possibility that the assumed "K" factor was in error.

Accordingly, 25 devices from the contract test units and five devices from the original correlation units were measured for VBE temperature coefficient in circulating deionized water at room ambient and at approximately 85°C (See Tables 3.5 and 3.6). The mean "K" factor for the contract test units was calculated to be -1.84mW/°C while the five original correlation units averaged -1.87mW/°C.

To obtain additional verification of this new "K" factor value, twenty of the original correlation units were measured on a "TACT" automatic parameter tester on VBE at 2mA in moving air at room temperatures from 25.2°C through 200°C to simulate the proposed JPL Accelerated Test Program (See Table 3.7). A linear regression analysis was performed on this data and a slope of -1.84mV/°C was computed with a correlation coefficient of 0.996, which indicates a very good statistical fit to the observed data.

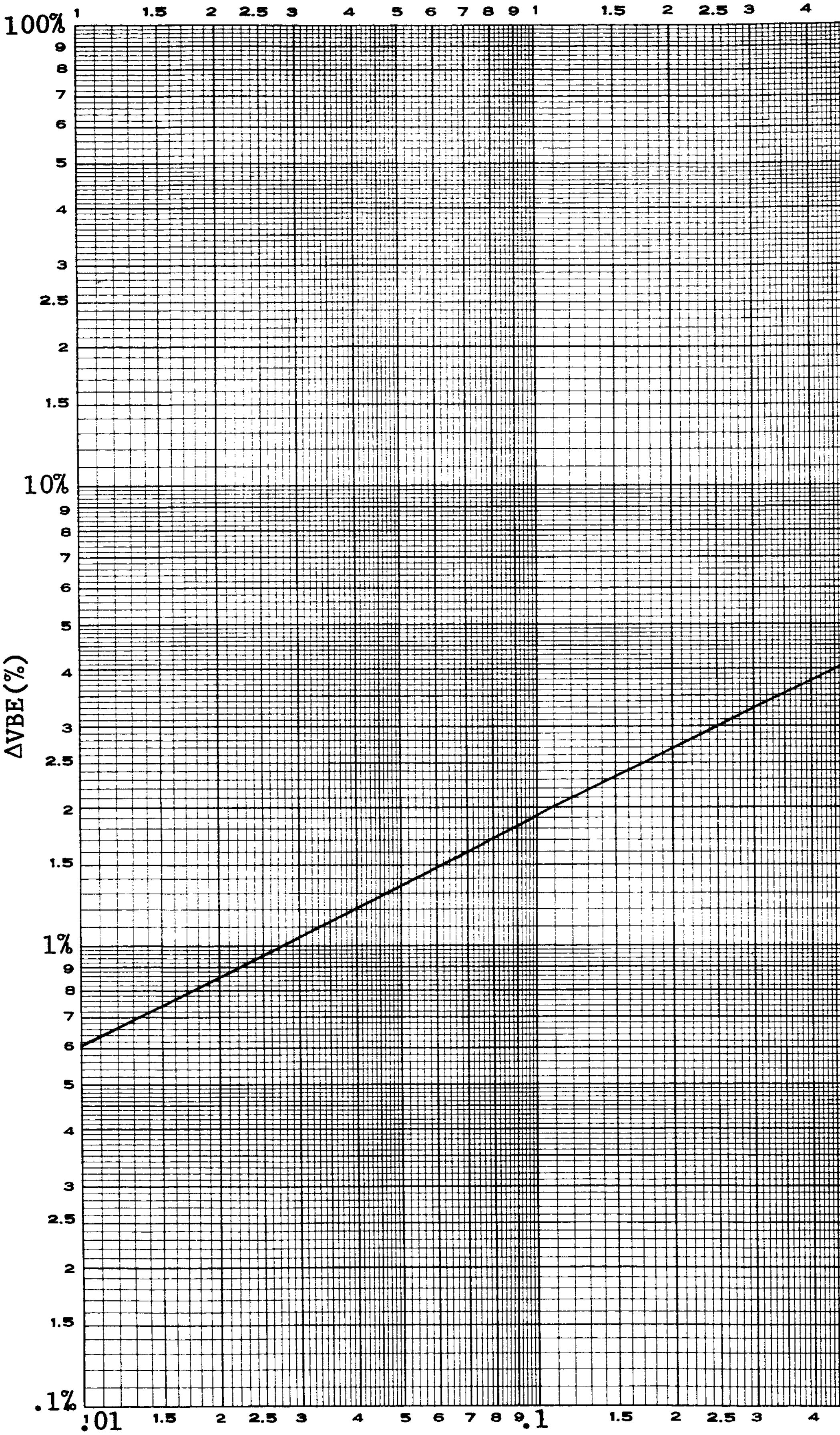
Since temperatures higher than 200°C would be encountered on the accelerated program, VBE data was taken on six of the twenty units previously tested up to 200°C on manual equipment with the devices in moving air at temperatures of 200°C, 250°C, and 300°C (See Table 3.8). This was to determine if any significant changes in the "K" factor occurred at the higher temperatures. No significant change in the slope was observed.

Using the value of "K" factor confirmed by four independent tests (Tables 3.5, 3.6, and 3.8), the data in Table 3.4 indicated that the bench tester readings were indeed correct. The 102mV ΔVBE for unit 115 converted to a θJ-C of 110.9°C/W. The ΔTJ required was 55.4° which compared accurately with the 55.5°C actually measured. For unit 3, the 109mV converted to a θJ-C of 118.5°C/W. The ΔTJ required was 59.2° compared to the measured value of 58.7°C. The values of θJ-C with the sense relay "in" were approximately 7 - 10% in error.

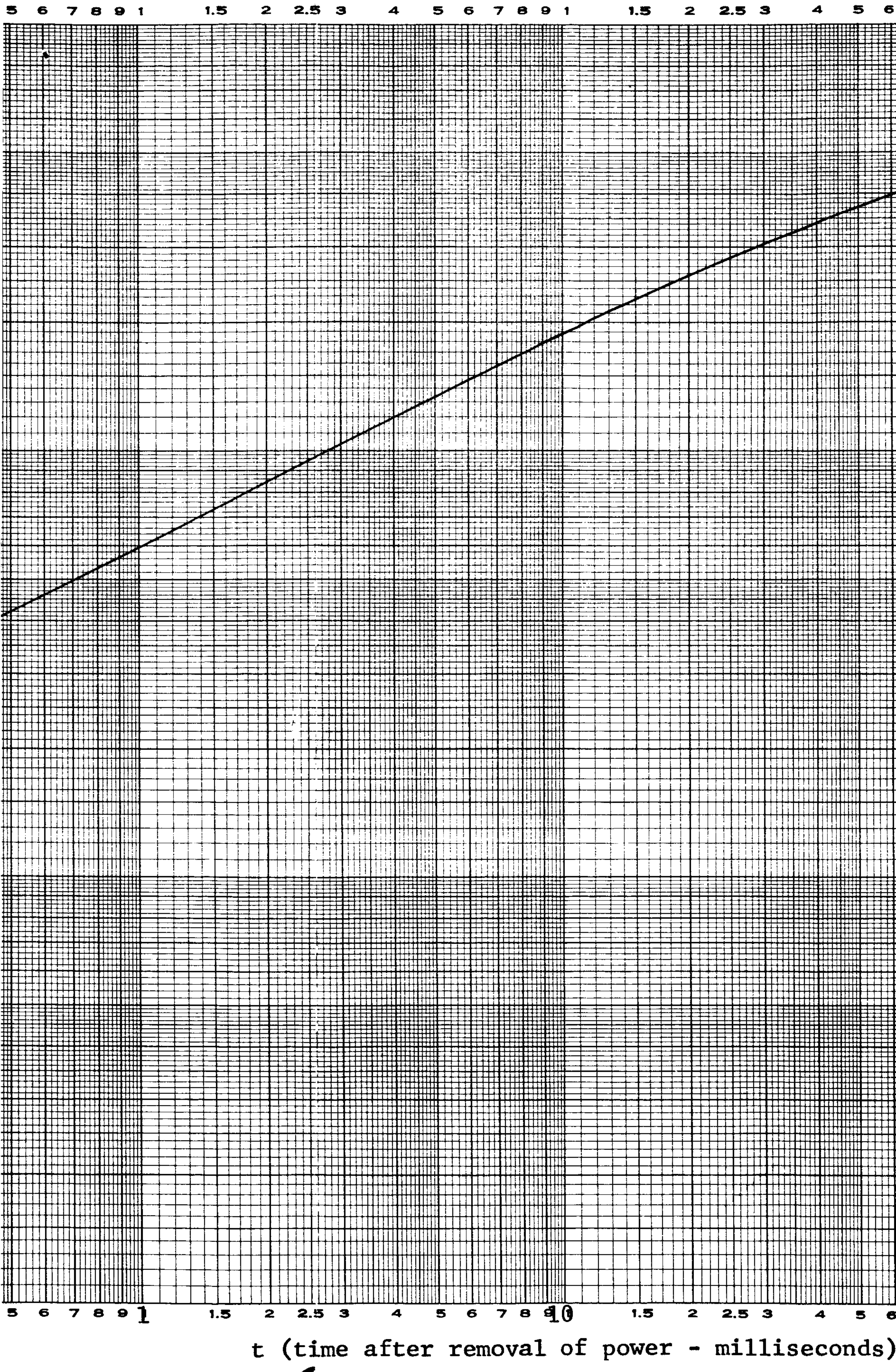
After the "K" factor experiments showed that the bench tester was capable of measuring θJ-C with a high degree of accuracy, an additional experiment was performed in an attempt to explain why tester HO-01 read so much lower than the bench tester. The Motorola Applications Department measured the thermal response characteristic for the 2N2222. This characteristic curve is shown in Figure 5. This curve showed that the decay in VBE following removal of power was at such a rate that a 1% error would be introduced if 27.5μseconds elapsed before the VBE was measured (or observed on scope). This error increased to 2% at 110μseconds, to 5% at 710μseconds, and to 10% at 2.8 milliseconds.

It appeared that the most probable reason for HO-01 to read much lower than the bench tester was a delay in sampling VBE following the 1-second power pulse. Since relays were used to control the timing, it was possible that delays of 1 to 3 milliseconds might be experienced. However, since the time required to change the relay circuitry and associated logic in tester HO-01 would have caused excessive delay in the program, alternate solutions were investigated.

The 25 original correlation units were again tested on the bench tester with the sensing relay contacts out and the new "K" factor of -1.84mV/°C used in computing θJ-C. The units were tested at the 500mW and 750mW power levels (See Table 3.9). Prior to this set of measurements the test socket had a buildup of corrosion due to being immersed repeatedly in the circulating water bath. Erratic waveforms were observed on the scope during the nulling step and this was traced to the contamination of the socket contacts. The socket was thoroughly cleaned and the deionized water replaced prior to making the measurements shown in Table 3.9. The mean value of θJ-C at 500mW was calculated to be 116.8°C/W and at 750mW, it was 115.3°C/W. This represented a difference of only



100%
10%
1%
.1%
ΔVBE (%)
.01
.1


5 6 7 8 9 1 1.5 2 2.5 3 4 5 6 7 8 9 1 1.5 2 2.5 3 4 5 6
5 6 7 8 9 1 1.5 2 2.5 3 4 5 6 7 8 9 10 1.5 2 2.5 3 4 5 6
t (time after removal of power - milliseconds)

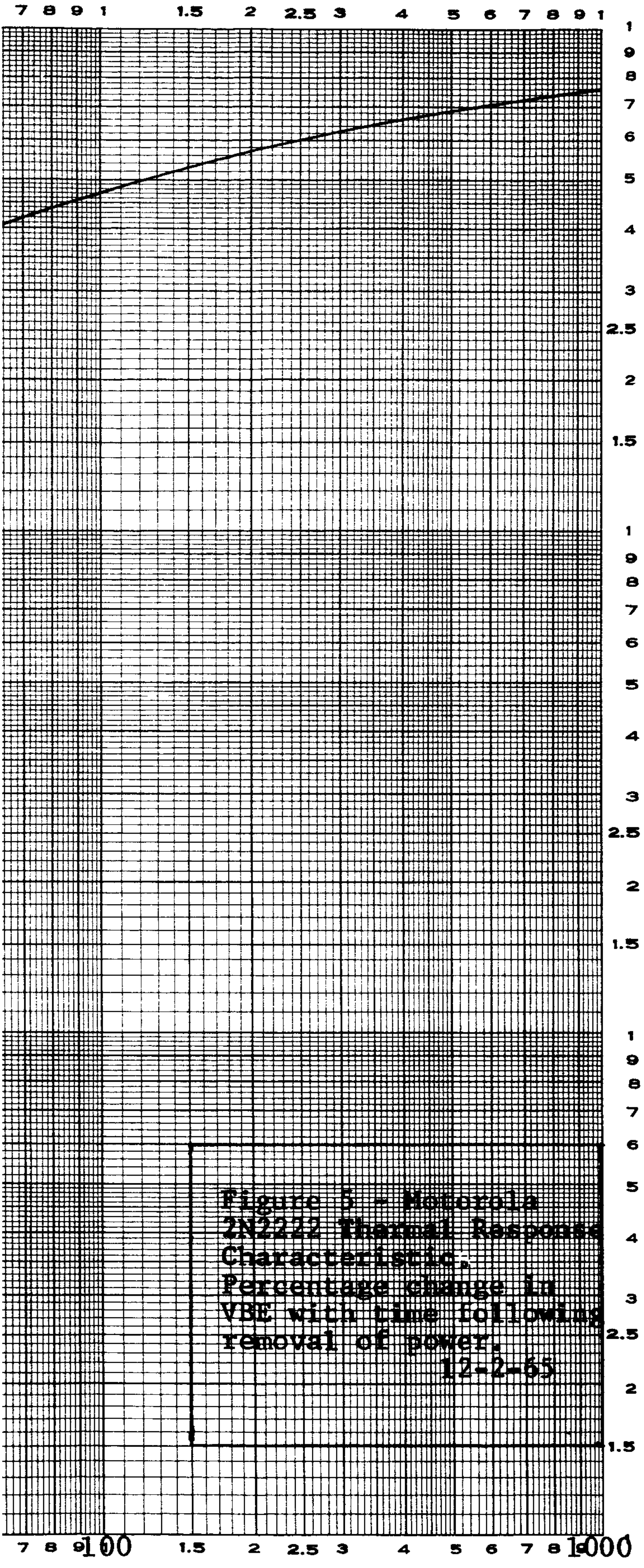


Figure 5 - Motorola 2N2222 Thermal Response Characteristic. Percentage change in VBE with time following removal of power.
12-2-65

1.25% between the two power levels and indicated that the original theory that θJ-C was essentially independent of power level was correct.

It was decided on the basis of the new and accurate results obtained on the bench tester that all 355 test units should be remeasured initially for θJ-C at 500mW on the bench tester. This was accomplished and the data is presented in Section 3.3. The first 25 program test units (not including the unwelded devices) were also tested at the 750mW level to permit an additional check of the power level effect in thermal resistance. The mean θJ-C value for the first 252 test devices measured at 500mW was 119.3°C/W. The mean value of θJ-C for the first 25 units measured at 750mW was 119.4°C/W. It was concluded from this experiment that the thermal impedance is independent of power within the range of power levels to be used in the Accelerated Test Program.

Since the bench tester required immersion of the test device in circulating deionized water and was also very slow, it would not be practical for large-scale testing such as that to be required on the proposed JPL Accelerated Test Program and in instances where devices could not be immersed (cap removed, etc.). Therefore, additional tests were performed to see if correlation could be achieved between tester HO-01 and the bench tester. The 25 original correlation devices were retested two times on HO-01 (See Table 3.9) with the scale factor changed. Comparing individual devices, the largest difference between HO-01 and bench readings was 5% for unit 23. The repeatability between the means of the two measurements on HO-01 was ±0.5%. For individual devices, the largest difference was ±2% for unit 12.

Twelve of the first 25 test units (not including the unwelded devices) were retested on HO-01 with the scale factor adjusted (dial reading of 1.020) for correlation of θJ-C values between the two testers. This data is presented in Table 3.11 and dated 12-4. Data was also taken on twenty of the same 25 test units with the original scale factor (dial reading of 1.500) and with the changed scale factor evaluated (dial reading of 1.085) using the original correlation devices. This data is also presented in Table 3.11 under the 12-4 date. Data on the same 25 test devices taken on the bench tester on 11-26 when all 355 test units were given their initial θJ-C measurements is also shown in Table 3.11 to show the correlation achieved. The mean θJ-C value of tester HO-01 readings with dial setting of 1.02 was calculated to be 118.67°C/W while the mean θJ-C value of the bench tester measurements was 118.69°C/W. On individual devices, the maximum difference between HO-01 and bench θJ-C values was 3.9% for unit 113. The mean of the differences between individual readings was 1.7%.

Since the correlation looked extremely good, the majority of the 355 devices were retested to obtain an accurate initial θJ-C value from tester HO-01. Some devices had already been started on other phases of the program and were not available for this retesting.

During the period the scale factor evaluation tests were being performed, the Motorola Applications Department measured θJ-C and θC-A on four of the original correlation units using a cold water and hot water bath ΔVBE comparison technique similar to the one used by the Reliability Programs Department to obtain the data previously presented in Table 3.4. The data obtained by the Applications Department is presented in Table 3.10 with the Reliability Programs Department values. The comparison of readings showed that θJ-C values on two of the units differed by only 2.5%, on one unit by 5.6%. The last device apparently had been damaged, or an error made in measurement since the Applications Department reading was 18% less than the one made by the Reliability Programs Department. For the other units, however, the correlation with an independent tester was satisfactory.

Six of the twelve units used for correlating tester HO-01 with the bench tester on 12-4 were retested on 12-17 and 12-18 to determine if the correlation had changed significantly. The data is presented in Table 3.11. No statistically significant change in correlation was observed.

One additional modification was made in the bench tester during the balance of the program. It was observed while testing θJ-A in free air that a small rise was occurring in both junction temperature (TJ) and case temperature (TC) in the "power off" condition. Investigation showed that although the emitter current was reduced to 2mA (I sense) when the power switch was turned off, the collector circuit was still connected and IC of 2mA was flowing. With the 12.5 volt VCE supply, this produced an average collector dissipation of 23mW (90% duty cycle) which was causing the observed temperature rise. The circuit was modified by using an additional set of contacts on the power on/off switch to interrupt the collector current in the "power off" position. This change is included in the circuit shown in Figure 4.

3.2 Initial Group A Measurements

Prior to processing the test devices for this program through the final welding operation, a 100% microscopic visual inspection was performed. Those devices which had any significant variation in the surface conditions of the aluminum metallization different from standard product were rejected. This was to insure a relatively homogeneous test lot for the thermal resistance studies.

Prior to any thermal resistance measurements, all test devices were measured on ten standard Group A d-c parameters. This was to insure that only devices meeting the 2N2222 electrical parameter specifications would be used in the program. The parameters measured, measurement conditions, and specification limits are shown in Table 3.12. This table is a copy of the actual programming sheet that accompanied the devices to the Fairchild "500" automatic tester on which the Group A measurements were performed. All electrical parameter data was automatically punched into IBM data cards by the Fairchild tester and processed for rejects on a GE-215 computer.

3.3 Initial θJ-C Measurements

The initial measurements of θJ-C at 500mW and 750mW power levels on the 335 test devices were performed on Motorola Quality Control tester HO-01 during the period of 11-5-65 through 11-16-65.

Following a thorough investigation of θJ-C accuracy and correlation, it was decided by Motorola that the initial θJ-C data should also be taken on the Quality Control bench tester at the 500mW level. These measurements were performed on 11-26-65. The first 67 devices could not be tested on the bench tester as they were unwelded (no cap) devices. Also, some of the remaining 288 devices had already started other testing and were not available for this measurement.

The θJ-C measurements data for both the HO-01 readout and the bench readout are presented in Tables 3.13 and 3.14.

The details of the initial correlation investigations are contained in Section 3.1 of this report.

3.4 Modifications in Measurement Techniques

This section summarizes the basic modification in equipment and/or techniques that were made on the two thermal resistance testers used on the program. The details are discussed in Section 3.1.

For Quality Control tester HO-01, the following modifications in equipment and/or measurement techniques were completed:

1. Corrected operating power level to allow for additional 2.0mA of sense current flowing in collector circuit but not indicated on tester.

2. Set 12.5 volts VCE with calibrated oscilloscope between collector and emitter rather than depend on accurately setting up an 11.8 volt VCB on a 50 volt full-scale 3% panel meter and assuming a VBE value of 0.7 volts.

3. Used sense current level of 2.0mA rather than 100μA to operate on a linear portion of the base-emitter diode forward characteristic curve.

4. Corrected scale factor by changing dial value from 1.50 to 1.02. This change included correction for the change in "K" factor (from 2.0 to 1.84) and for the apparent time delay in the sampling of VBE at the end of the 1-second power pulse.

For the Quality Control bench tester, the following modifications in equipment and/or measurement techniques were completed:

1. Removed sensing relay contacts from scope circuit monitoring VBE and viewed VBE directly on scope through differential amplifier. This permitted observation of the full exponential decay waveform of VBE immediately following the removal of power.

2. After completion of Item 1, the phase control was adjusted in such a manner as to observe VBE within 1μsecond after the power was removed.

3. Changed "K" factor used in calculating θJ-C from -2.00mV/°C to -1.84mV/°C.

4. Reduced socket contamination and corrosion by cleaning socket and changing deionized water frequently.

5. Twisted leads to measurement socket to eliminate tendency of circuit to have random oscillations.

6. Modified power on/off switch to reduce actual "power off" condition from 23mW to approximately 1.4mW.

3.5 Corrected Initial θJ-C Data

After completion of the initial correlation studies described in Section 3.1 of this report, good correlation was obtained between Quality Control tester HO-01 and the Quality Control bench tester.

Since some tests on this program could not be performed on HO-01 because of the water immersion requirement (the unwelded units), and because the repeatability experiment would involve 1000 individual measurements which would be similar to the requirements of the proposed JPL Accelerated Test Program, it was decided to retest the majority of the 355 test devices on tester HO-01 at 500mW power level with the scale correction. Some devices were already in testing and not available for this measurement. These measurements were performed during the period of 12-4-65 through 12-6-65.

The θJ-C measurements data for the retest on HO-01 are presented in Tables 3.15 and 3.16.

THERMAL RESISTANCE DATA

TABLE 3.1

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 (SL3-05)
GROUP REY 098 SUBGROUP Correlation Unit

First θJ-C* data taken on H0-01 and Bench Tester with 25 correlation samples.

DIAL:	750		150		225		"K" factor=-2.0v/°c (estimated)				
IC :	20mA		40mA		80mA		20mA		40mA		80mA
VCE :	12.5V		12.5V		9.38V		12.5V		12.5V		9.38V
S/N	θJ-C at 250mw	ΔTC at 250mw	θJ-C at 500mw	ΔTC at 500mw	θJ-C at 750mw	ΔTC at 750mw	θJ-C at 250mw		θJ-C at 500mw		θJ-C at 750mw
UNIT	°c/mw	°c	°c/mw	°c	°c/mw	°c	°c/mw		°c/mw		°c/mw
MINIMUM											
MAXIMUM											
1	.164		.0930		.0867		---		---		---
2	.139		.0842		.0804		.090		.095		.102
3	.128		.0870		.0809		.094		.096		.102
4	.129		.0830		.0758		.080		.088		.094
5	.150		.0943		.0875		.104		.104		.108
6	.171		.0936		.0885		.100		.103		.107
7	.115		.0839		.0803		.092		.093		.100
8	.132		.0901		.0847		.094		.097		.106
9	.138		.0847		.0813		.091		.096		.102
10	.208		.1000		.0944		.104		.107		.113
11	.137		.0923		.0850		.096		.100		.106
12	.158		.0899		.0845		.098		.098		.105
13	.154		.0870		.0787		.086		.091		.097
14	.167		.0836		.0765		.087		.090		.097
15	---		---		---		---		---		---
16	.136		.0851		.0798		.092		.096		.102
17	.146		.0898		.0815		.093		.097		.102
18	.199		.0953		.0876		.092		.097		.105
19	.162		.1030		.0957		.107		.112		.118
20	.132		.0923		.0869		.096		.101		.107
21	.148		.0863		.0778		.090		.094		.097
22	---		---		---		.084		.089		.094
23	---		---		---		.091		.097		.100
24	---		---		---		.104		.110		.117
25	.180	+2.0°	.0810	+5.0°	.0760	+6.5°	.088		.098		.102
DATE	10-28	11-19	10-28	11-19	10-28	11-19	11-2		11-2		11-2
STATION	H0-01	H0-01	H0-01	H0-01	H0-01	H0-01	Bench		Bench		Bench
INSP. STAMP						Page 3-23					

REMARKS * θJ-C data taken with sense current of 2.0mA on both H0-01 and Bench tester.

NAME
TITLE
DATE

THERMAL RESISTANCE DATA

TABLE 3.2

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 (SL3-05)
GROUP REY 098 SUBGROUP Correlation Unit

Retest of selected units on Bench for Repeatability check and evaluation of 1st circuit change

K Factor = -2.0mv/°c (estimate)

Effect on 500 mw θJ-C of disconnecting sensing relay.

IC :	20mA		40mA		80mA				40mA		
VCE:	12.5V		12.5V		9.38V				12.5V		
S/N	θJ-C at 250mw		θJ-C at 500mw		θJ-C at 750mw				θJ-C at 500mw		
UNIT	°C/mw		°C/mw		°C/mw				°C/mw		
MINIMUM											
MAXIMUM											
1											
2	.089		.095		.097				.102		
3											
4											
5	.098		.102		.105				.108		
6											
7											
8											
9											
10	.105		.107		.110				.114		
11											
12											
13											
14	.086		.087		.093				.094		
15											
16											
17											
18											
19											
20	.096		.098		.103				.105		
21											
22											
23											
24											
25	.092		.096		.098				.103		
DATE	11-4		11-4		11-4				11-10		
STATION	Bench		Bench		Bench				Bench		
INSP. STAMP						Page 3-24					

REMARKS

NAME

TITLE

DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.3

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 (SL3-05)
GROUP REY 098 SUBGROUP Correlation Unit

Test to Determine if rise in TC on H0-01 was causing significant error in θJ-C.*

	Unit #2		Unit #4		Unit #5		Unit #6		Unit #7	
	θJ-C at 500mw		θJ-C at 500mw		θJ-C at 500mw		θJ-C at 500mw		θJ-C at 500mw	
R/O	Still Air at 26°C	Water Bath at 24°C	Still Air at 26°C	Water Bath at 24°C	Still Air at 26°C	Water Bath at 24°C	Still Air at 26°C	Water Bath at 24°C	Still Air at 26°C	Water Bath at 24°C
UNIT	°c/mw	°c/mw	°c/mw	°c/mw	°c/mw	°c/mw	°c/mw	°c/mw	°c/mw	°c/mw
MINIMUM										
MAXIMUM										
1st	.0763	.0762	.0722	.0731	.0857	.0854	.0778	.0782	.0731	.0748
2nd	.0774	.0753	.0698	.0702	.0811	.0840	.0741	.0719	.0745	.0721
3rd	.0750	.0744	.0696	.0708	.0819	.0822	.0746	.0762	.0708	.0661
4th	.0769	.0711	.0719	.0676	.0847	.0873	.0743	.0738	.0744	.0723
5th	.0740	.0705	.0721	.0673	.0858	.0854	.0775	.0821	.0742	.0719
6th	.0779	.0728	.0702	.0687	.0809	.0810	.0750	.0713	.0758	.0717
7th	.0745	.0730	.0712	.0715	.0811	.0796	.0743	.0729	.0734	.0715
8th	.0744	.0739	.0711	.0682	.0819	.0792	.0752	.0733	.0736	.0734
9th	.0753	.0719	.0696	.0680	.0815	.0822	.0740	.0705	.0747	.0708
10th	.0747	.0725	.0708	.0694	.0826	.0824	.0739	.0752	.0715	.0723
DATE	11-29	11-29	11-29	11-29	11-29	11-29	11-29	11-29	11-29	11-29
STATION	H0-01	H0-01	H0-01	H0-01	H0-01	H0-01	H0-01	H0-01	H0-01	H0-01
INSP. STAMP						Page 3-25				

REMARKS (*) Before any changes in measurement method.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1070

MOTOROLA INC.
Semiconductor
Products Division

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 & 544 (SL3-05)
GROUP REY 098 SUBGROUP Correlation Units

THERMAL RESISTANCE DATA
TABLE 3.4

Measurement of θJ-C with transistor case inserted in thermoelectric (T/E) cooler.

"K" Factor=-2.0mv/°c (estimate) TC (Hot & Cold) controlled by T/E cooler to obtain VBE of 102mv & 109mv.
IC=40mA
VCE=12.5V

S/N		ΔVBE at 500mw	θJ-C at 500mw		TC Cold	VBE Cold	TC Hot	VBE Hot		ΔVBE at 500mw	θJ-C at 500mw
		Sense Relay "out"								Sense Relay "in"	
UNIT		mv	°c/w		°C	Volts	°C	Volts		mv	°c/w
MINIMUM											
MAXIMUM											
115		102	102		22.4	.699	77.9	.597		94.4	94.4
3		109	109		23.1	.685	81.8	.576		98.8	98.8
DATE		11-12	11-12		11-12	11-12	11-12	11-12		11-12	11-12
STATION		Bench	Bench		Bench	Bench	Bench	Bench		Bench	Bench
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.5

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 541 (SL3-05)
GROUP REY 098 SUBGROUP Z01 (Water-Bath)

Data for verification of VBE temperature coefficient - Water Bath Method.

VBE measured at IE = 2.0mA, IC = 0
Device immersed in circulating de-ionized water.

S/N	TW Cold Water		VBE Cold		TW Hot Water		VBE Hot				
UNIT	°C		Volts		°C		Volts				
MINIMUM											
MAXIMUM											
101	24.75		.698		85.13		.584				
102	24.22		.681		84.91		.569				
103	24.75		.690		86.65		.576				
104	25.00		.699		86.65		.584				
105	25.00		.700		86.68		.588				
106	25.25		.694		85.78		.580				
107	25.25		.691		84.91		.580				
108	25.25		.690		84.91		.580				
109	25.25		.699		85.13		.586				
110	-----		----		-----		----				
111	25.25		.691		84.69		.582				
112	25.25		.692		84.69		.581				
113	25.25		.698		84.69		.587				
114	25.25		.692		84.69		.583				
115	25.25		.694		84.69		.583				
116	25.25		.699		84.47		.589				
117	25.25		.698		84.47		.588				
118	25.25		.691		84.47		.583				
119	25.25		.691		84.02		.582				
120	25.25		.699		83.81		.590				
121	25.25		.690		83.59		.581				
122	25.25		.691		83.59		.583				
123	25.25		.694		83.37		.588				
124	25.25		.696		83.37		.588				
125	25.25		.692		82.93		.587				
DATE	11-22		11-22		11-22		11-22				
STATION	Bench		Bench		Bench		Bench				
INSP. STAMP						Page 3-27					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.6

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 (SL3-05)
GROUP REY 098 SUBGROUP Z01 (Water-Bath)

Data for verification of VBE temperature coefficient - water bath method.

VBE measured at IE=2.0mA, IC=0
Device immersed in circulating de-ionized water.

S/N	TW Cold Water		VBE Cold		TW Hot Water		VBE Hot				
UNIT	°C		Volts		°C		Volts				
MINIMUM											
MAXIMUM											
2	23.78		.681		86.22		.563				
4	23.78		.691		85.35		.579				
5	23.78		.683		84.91		.570				
6	23.78		.687		84.91		.573				
7	23.78		.688		84.47		.570				
DATE	11-23		11-23		11-23		11-23				
STATION	Bench		Bench		Bench		Bench				
INSP. STAMP						Page 3-28					

REMARKS

NAME

TITLE

DATE

MOTOROLA FORM NO. SPD-1079

PAGE 001 DATE 02/01/66 MOTOROLA SEMICONDUCTOR
RE NO REY-098-Z01 JPL θJ-C PROGRAM
DEVICE 2N2222 VBE K-FACTOR TEST
LOT NO 544 READOUT 01
DEVICE CODE SL3-05 READOUT 01
TEST DATE 11/24/65

UNIT	25.2C	50C	75C	100C	125C	150C	175C	200C
00002	06841-04	06340-04	05892-04	05427-04	04972-04	04508-04	04040-04	03560-04
00004	06933-04	06435-04	05994-04	05764-04	05088-04	04640-04	04180-04	03698-04
00005	06849-04	06357-04	05907-04	05464-04	05016-04	04560-04	04099-04	03614-04
00006	06921-04	06434-04	05997-04	05551-04	05107-04	04650-04	04196-04	03712-04
00007	06873-04	06374-04	05923-04	05453-04	04996-04	04530-04	04062-04	03579-04
00008	06874-04	06370-04	05915-04	05450-04	04993-04	04530-04	04060-04	03578-04
00009	06872-04	06384-04	05950-04	05506-04	05059-04	04597-04	04134-04	03654-04
00010	06991-04	06519-04	06096-04	05649-04	05213-04	04751-04	04296-04	03806-04
00011	06865-04	06359-04	05916-04	05442-04	04976-04	04518-04	04045-04	03571-04
00012	06791-04	06287-04	05860-04	05396-04	04943-04	04482-04	04015-04	03539-04
00013	06994-04	06513-04	06082-04	05630-04	05171-04	04721-04	04255-04	03766-04
00014	06886-04	06400-04	05971-04	05521-04	05075-04	04613-04	04163-04	03680-04
00016	06861-04	06361-04	05933-04	05463-04	05002-04	04540-04	04063-04	03583-04
00017	06837-04	06343-04	05917-04	05447-04	04986-04	04529-04	04071-04	03588-04
00018	07087-04	06607-04	06189-04	05728-04	05279-04	04831-04	04367-04	03883-04
00019	06836-04	06333-04	05910-04	05441-04	04977-04	04516-04	04056-04	03575-04
00020	06879-04	06373-04	05941-04	05450-04	04983-04	04523-04	04052-04	03570-04
00021	06776-04	06276-04	05860-04	05382-04	04925-04	04476-04	04008-04	03531-04
00022	06906-04	06421-04	05992-04	05534-04	05075-04	04629-04	04184-04	03694-04
00023	06972-04	06490-04	06084-04	05626-04	05187-04	04732-04	04271-04	03793-04

DATA CODE: 5 digits with negative power of ten multiplier - units are volts - parameter is VBE @ 2mA (Example: 06972-04 = 0.6972 volts)

TABLE 3.7

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 (SL3-05)
GROUP REY 098 SUBGROUP Z01 (200-300°C)

TABLE 3.8

Data for calculating VBE temperature coefficient ("K" Factor) in range up to 300°C.

VBE measured at IE = 2.0mA, IC = 0

S/N	VBE* at 25°C		VBE* at 200°C		VBE at 27°C		VBE at 200°C		VBE at 250°C		VBE at 300°C
UNIT	Volts		Volts		Volts		Volts		Volts		Volts
MINIMUM											
MAXIMUM											
8	.6874		.3578		.682		.352		.262		.171
12	.6791		.3539		.675		.348		.261		.172
14	.6886		.3680		.684		.360		.270		.178
16	.6861		.3583		.682		.353		.263		.174
17	.6837		.3588		.680		.353		.267		.177
23	.6972		.3793		.693		.372		.282		.190
DATE	11-24		11-24		11-30		11-30		11-30		11-30
STATION	TACT		TACT		Bench		Bench		Bench		Bench
INSP. STAMP						Page 3-30					

REMARKS* Reference for relating 200 - 300°C data to previous readings taken between 25°C and 200°C on 11-24-65.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.9

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 (SL3-05)
GROUP REY 098 SUBGROUP Correlation Unit

Bench Tests with sensing relay omitted &"K" Factor modified-HO-01 Test with scale change.

"K" Factor=-1.84mv/°c(measured & verified)

IC :			40mA				80mA	IC : 42mA			42mA
VCE:			12.5V				9.38V	VCE : 11.9V			11.9V
								DIAL: 1.085			1.085
S/N	ΔVBE at 500mw		θJ-C at 500mw		ΔVBE at 750mw		θJ-C at 750mw		θJ-C at 500mw		θJ-C at 500mw
UNIT	mv		°c/w		mv		°c/w		°c/w		°c/w
MINIMUM											
MAXIMUM											
1	---		---		---		---		---		---
2	108		118		160		116		104		105
3	---		---		---		---		---		---
4	98		107		145		105		96		97
5	112		122		168		122		114		114
6	106		115		158		115		106		105
7	104		113		156		113		102		103
8	108		118		162		117		104		106
9	113		123		167		121		115		114
10	117		127		173		125		117		118
11	111		121		165		120		112		110
12	111		121		161		117		107		111
13	102		111		150		109		101		102
14	99		108		142		103		98		98
15	---		---		---		---		---		---
16	107		116		153		111		102		103
17	109		119		164		119		105		107
18	108		118		163		118		111		112
19	122		133		186		135		122		123
20	109		119		163		118		108		109
21	101		110		150		109		99		100
22	97		106		144		104		97		99
23	101		110		150		109		104		106
24	---		---		---		---		---		---
25	---		---		---		---		---		---
DATE	11-24		11-24		11-24		11-24		12-3		12-4
STATION	Bench		Bench		Bench		Bench		HO-01		HO-01
INSP. STAMP						Page 3-31					

REMARKS

NAME

TITLE

DATE

THERMAL RESISTANCE DATA

TABLE 3.10

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 (SL3-05)
GROUP REY 098 SUBGROUP Correlation Unit

Correlation Data -comparison of H0-01 Bench & Motorola Applications Dept. equipment.

RPD TEST DATA					Applications Department Test Data (Basically a Water - Bath Method)						
S/N	θJ-C on H0-01*		θJ-C on Bench**		θJ-C		θJ-A		θC-A		
UNIT	°c/w		°c/w		°c/w		°c/w		°c/w		
MINIMUM											
MAXIMUM											
4	77		107		113		319		206		
6	82		115		112		300		188		
7	79		113		93		306		213		
8	84		118		115		324		210		
DATE	11-24		11-24		12-3		12-3		12-3		
STATION	H0-01		Bench		Appl.		Appl.		Appl.		
INSP. STAMP						Page 3-32					

REMARKS * Before any changes in measurement method.
** With sensing relay disconnected and -1.84mv/°c "K" factor.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.11

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Correlation Unit

Adjustment of H0-01 Scale Factor for Correlation with Bench Tester.

DIAL:	---		1.500		1.085		1.020		1.020		1.020
IC :	40mA		42mA		42mA		42mA		42mA		42mA
VCE :	12.5V		11.9V		11.9V		11.9V		11.9V		11.9V
S/N	θJ-C* at 500mw		θJ-C at 500mw		θJ-C at 500mw		θJ-C at 500mw		θJ-C at 500mw		θJ-C at 500mw
UNIT	°c/w		°c/w		°c/w		°c/w		°c/w		°c/w
MINIMUM											
MAXIMUM											
101	115		---		---		---		---		---
102	---		---		---		---		---		---
103	120		---		---		117		---		---
104	118		77		109		116		---		---
105	124		83		113		120		120		122
106	124		83		117		123		---		---
107	120		81		111		120		---		---
108	113		79		106		114		---		---
109	109		---		---		109		107		108
110	---		---		---		---		---		---
111	126		86		119		129		127		126
112	113		77		105		115		---		---
113	129		87		119		134		129		127
114	116		78		110		---		---		---
115	113		74		104		---		---		---
116	113		72		103		109		108		107
117	117		78		109		---		---		---
118	124		81		113		---		---		---
119	116		75		106		---		---		---
120	131		87		121		---		---		---
121	117		77		107		---		---		---
122	118		78		109		118		115		114
123	128		83		114		---		---		---
124	108		71		101		---		---		---
125	121		79		108		---		---		---
DATE	11-26		12-4		12-4		12-4		12-17		12-18
STATION	Bench		H0-01		H0-01		H0-01		H0-01		H0-01
INSP. STAMP						Page 3-33					

REMARKS (*) Sensing relay omitted & "K" factor=-1.84mv/°c.

NAME
TITLE
DATE

[redacted] PROJ. [redacted]30 [redacted] 1 [redacted]

PNP	NPN	DEVICE						SPACE	LOT NO.				SPACE	RE-NO.				SPACE	CODE	SPACE	DATE				SPACE
PROD. LINE		2	N	2	2	2	2			5	4	4		Y	0	9	8				11	0	8	5	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		19					24

INITIAL READINGS FOR: R/O #01 | SAMPLE SIZE 288 | READ OUT: ON / OFF | N/A | N/A | N/A

SERIALIZED #'s 101-388 DATE TO LINE OFF LINE

TEST SEQ.	PARA.	CONDITIONS	LIMITS MIN	LIMITS MAX	NO. REJ.	TEST OPER.	DATE READ	EOL LIMITS MIN	EOL LIMITS MAX	NO. REJ.	TEST OPER.	DATE READ	NO. REJ.	TEST OPER.	DATE READ	NO. REJ.	TEST OPER.	DATE READ
1	ICBO1	VCB=50V, IE=0	-	10nA														
	1 0	5 0 0 2 0 0 0 0																
2	IEBO1	VEB=3V	-	10nA														
	1 1	0 3 0 2 0 0 0 0																
3	BVCBO1	IC=10µA, IE=0	60V	-														
	3 0	1 0 0 5 0 0 0 0																
4	BVEBO1	IE=10µA, IC=0	5V	-														
	3 1	1 0 0 5 0 0 0 0																
5	BVCEO1	IC=150mA, IB=0	30V	-														
	3 4	9 9 9 7 0 0 0 0																
6	VCE (S)1	IC=150mA, IB=15mA	-	.4V														
	8 1	0 1 0 0 1 5 0 9																
7	VBE (S)1	IC=150mA, IB=15mA	-	1.3V														
	8 5	0 1 0 0 1 5 0 9																
8	hFE1	IC=1mA, VCE=10V	50	-														
	7 0	1 0 0 2 1 0 0 7																

NOTES:

(1) Use Autonetics Format and 12 Parameter Cards (Columns 21-80)

(2) Use Test Fixture #15

(3) Use Clamp #8 C-E and short B-E

(4) Before testing sample, read and record 5 correlation units and check readings with upper and lower limit cards supplied by RPD. If any reading is out of limits, call RPD (ext. 6507).

(5) Mark Date Tested on 5 correlation cards and keep with sample cards.

TABLE 3.12

PNP	NPN	DEVICE						SPACE	LOT NO.				SPACE	RE-NO.				SPACE	CODE	SPACE	DATE				SPACE
	X																								
PROD. LINE		2	N	2	2	2	2			5	4	4		Y	0	9	8				11	0	8	5	
SL-3-05		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		19					24

INITIAL READINGS FOR: R/O #01 SAMPLE SIZE 288

SERIALIZED #'s 101-388 DATE TO LINE OFF LINE

TEST SEQ.	PARA.	CONDITIONS	LIMITS MIN	LIMITS MAX	NO. REJ.	TEST OPER.	DATE READ	READ OUT ON / EOL LIMITS MIN	READ OUT OFF / EOL LIMITS MAX	N/A NO. REJ.	TEST OPER.	DATE READ	N/A NO. REJ.	TEST OPER.	DATE READ	N/A NO. REJ.	TEST OPER.	DATE READ
9	hFE2	IC=10mA, VCE=10V	75	-														
	7 0	1 0 0 2 1 0 0 8																
10	hFE3	IC=150mA, VCE=10V	100	300														
	7 1	1 0 0 2 1 5 0 9																

TABLE 3.12 (Cont'd)

THERMAL RESISTANCE DATA

TABLE 3.13

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL3-05)
GROUP REY 098 SUBGROUP Initial θJ-C

Initial readout of θJ-C on Q.C. tester H0-01* for unwelded devices.

DIAL: 1.5
IC : 42mA
VCE : 11.9V

No initial readout was performed on Bench tester since the unwelded (NO CAP) units could not be immersed in water.

S/N	θJ-C at 500mw									
UNIT	°c/w									
MINIMUM										
MAXIMUM										
1	.0704									
2	.0732									
3	.0746									
4	.0728									
5	.0676									
6	.1248									
7	.0740									
8	.0778									
9	.0710									
10	.0735									
11	.0740									
12	.0737									
13	.0693									
14	.0738									
15	.0720									
16	.0818									
17	.0737									
18	.0730									
19	.0715									
20	.0701									
21	----									
22	.0720									
23	.0763									
24	.0790									
25	.0728									
DATE	11-5									
STATION	H0-01									
INSP. STAMP						Page 3-36				

REMARKS * 2mA sense current used.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.13 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL3-05)
GROUP REY 098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
26	.0736										
27	.0730										
28	.0716										
29	.0731										
30	.0705										
31	.0744										
32	.0743										
33	-----										
34	.0730										
35	.0698										
36	.0721										
37	.0723										
38	.0860										
39	.0756										
40	.0740										
41	.0702										
42	.0730										
43	.0718										
44	-----										
45	.0781										
46	.0895										
47	.0744										
48	.0725										
49	.0626										
50	-----										
DATE	11-5										
STATION	HO-01										
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.13 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544(SL3-05)
GROUP REY 098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
51	.0742										
52	.0738										
53	.0715										
54	.0720										
55	.0715										
56	.0717										
57	.0841										
58	.0692										
59	.0678										
60	.0691										
61	.0690										
62	.0784										
63	.0746										
64	.0768										
65	.0810										
66	.0768										
67	.0817										
DATE	11-5										
STATION	HO-01										
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.14

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (S13-05)
GROUP REY098 SUBGROUP Initial θJ-C

Initial R/O - Q.C. Tester H0-01*					Initial R/O - RPD Bench Tester **						
DIAL:	1.5		2.25		"K" Factor = -1.84 mv/°C.						
IC :	42mA		82mA		40mA				82mA		
VCE :	11.9v		9.15V		12.5V				9.15V		
S/N	θJ-C at 500mw		θJ-C at 750mw		θJ-C at 500mw		ΔVBE at 500mw		θJ-C at 750mw		ΔVBE at 750mw
UNIT	°C/mw		°C/mw		°C/mw		mv		°C/mw		mv
MINIMUM											
MAXIMUM											
101	.0818		.0759		.115		106		.117		161
102	.0876		.0804		----		---		----		---
103	.0797		.0749		.120		110		.117		162
104	.0803		.0746		.118		109		.117		162
105	.0871		.0806		.124		114		.125		172
106	.0875		.0832		.124		114		.124		171
107	.0833		.0786		.120		110		.122		168
108	.0894		.0738		.113		104		.116		160
109	.0781		.0697		.109		100		.110		152
110	.0813		.0742		----		---		----		---
111	.0887		.0837		.126		116		.125		173
112	.0590		.0731		.113		104		.117		161
113	.0922		.0863		.129		119		.130		180
114	.0832		.0751		.116		107		.117		162
115	.0781		.0733		.113		104		.115		159
116	.0765		.0716		.113		104		.114		158
117	.0823		.0789		.117		108		.118		163
118	.0860		.0795		.124		114		.125		172
119	.0804		.0724		.116		107		.116		160
120	.0937		.0856		.131		120		.129		178
121	.0809		.0754		.117		108		.119		164
122	.0824		.0768		.118		109		.120		165
123	.0871		.0807		.128		118		.130		180
124	.0745		.0681		.108		099		.109		150
125	.0821		.0772		.121		111		.121		167
DATE	11-15		11-16				11-26				11-26
STATION	H0-01		H0-01				Bench				Bench
INSP. STAMP						Page 3-39					

REMARKS *2mA Sense Current used for both H0-01 and Bench
**"K" Factor of -1.84mv/°C used

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)

TABLE 3.14 (Cont'd)

GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
126	.0798		.0749		.113		104				
127	.0789		.0741		.117		108				
128	1.31		1.26		.174		160				
129	.0836		.0774		.121		111				
130	.0807		.0742		.116		107				
131	.0807		.0746		.116		107				
132	.0958		.0883		.135		124				
133	.0825		.0786		.113		104				
134	.0834		.0766		.110		101				
135	.0815		.0747		.121		111				
136	.0862		.0804		.124		114				
137	.0799		.0742		.118		109				
138	.0819		.0775		.120		110				
139	.0812		.0761		.116		107				
140	.0754		.0719		.110		101				
141	.0798		.0749		.113		104				
142	.0905		.0829		.120		110				
143	1.01		.0955		.137		126				
144	.0820		.0765		.121		111				
145	.0859		.0781		.120		110				
146	.0795		.0733		.113		104				
147	.0785		.0733		.111		102				
148	.0859		.0808		.128		118				
149	2.63		2.49		.321		295				
150	.0822		.0775		.124		114				
DATE	11-15		11-16				11-26				
STATION	H0-01		H0-01				Bench				
INSP. STAMP						Page 3-40					

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
151	.0817		.0765		.116		107				
152	.0810		.0766		.117		108				
153	.0787		.0738		.113		104				
154	.0792		.0724		.120		110				
155	.0781		.0719		.114		105				
156	.0792		.0760		.120		110				
157	.0780		.0708		.114		105				
158	10.6		10.6		----		---				
159	.0861		.0796		.124		114				
160	.0838		.0763		.122		112				
161	.0813		.0769		.121		111				
162	.0836		.0761		.122		112				
163	.0906		.0825		.125		115				
164	.0732		.0660		.109		100				
165	.0845		.0764		.125		115				
166	.0826		.0745		.122		112				
167	.0819		.0732		.120		110				
168	.0849		.0780		.121		111				
169	.0856		.0794		.123		113				
170	.0868		.0818		.126		116				
171	.0789		.0729		.114		105				
172	.0867		.0788		.128		118				
173	.0824		.0762		.116		107				
174	.0819		.0725		.113		104				
175	.0814		.0764		.120		110				
DATE	11-15		11-16				11-26				
STATION	HO-01		HO-01				Bench				
INSP. STAMP						Page 3-41					

REMARKS

NAME

TITLE

DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
176	.0857		.0801		.124		114				
177	.0852		.0778		.125		115				
178	.0868		.0831		.124		114				
179	.0869		.0787		.126		116				
180	.0788		.0749		.113		104				
181	.0799		.0755		.115		106				
182	.0859		.0801		.122		112				
183	.0771		.0733		.113		104				
184	.0836		.0759		.120		110				
185	.0781		.0724		.114		105				
186	.0752		.0719		.114		105				
187	.0860		.0777		.124		114				
188	.0789		.0724		.113		104				
189	.0839		.0780		.127		117				
190	.0775		.0732		.117		108				
191	.0817		.0778		.122		112				
192	.0789		.0735		.113		104				
193	.0827		.0747		.124		114				
194	.0849		.0791		.124		114				
195	.0860		.0802		.122		112				
196	.0799		.0731		.115		106				
197	.0799		.0748		.117		108				
198	.0793		.0735		.121		111				
199	.0824		.0785		.127		117				
200	.0777		.0717		.113		104				
DATE	11-15		11-16				11-26				
STATION	H0-01		H0-01				Bench				
INSP. STAMP						Page 3-42					

REMARKS

NAME

TITLE

DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
201	.0792		.0744		.123		113				
202	.0859		.0777		.125		115				
203	.0768		.0713		.112		103				
204	.0836		.0783		.122		112				
205	.0820		.0766		.120		110				
206	.0868		.0794		.121		111				
207	.0828		.0747		.118		109				
208	1.07		1.00		.154		142				
209	.0802		.0737		.123		113				
210	.0810		.0709		.115		106				
211	.0903		.0849		.130		120				
212	.0793		.0727		.124		114				
213	.0879		.0819		.132		121				
214	.0814		.0759		.116		107				
215	.0792		.0753		.115		106				
216	.0673		.0637		.104		96				
217	.0893		.0820		.123		113				
218	.0744		.0701		.114		105				
219	.0826		.0753		.122		112				
220	.0808		.0719		.116		107				
221	.0906		.0842		.127		117				
222	.0818		.0762		.118		109				
223	.0837		.0788		.121		111				
224	.0821		.0761		.118		109				
225	.0765		.0710		.107		98				
DATE	11-15		11-16				11-26				
STATION	H0-01		H0-01				Bench				
INSP. STAMP						Page 3-43					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
226	.0815		.0752		.117		108				
227	.0832		.0798		.123		113				
228	.0736		.0695		.109		100				
229	.0806		.0744		.117		108				
230	.0657		.0603		.099		91				
231	.0774		.0704		.111		102				
232	.0948		.0898		.136		125				
233	.0857		.0790		.117		108				
234	.0838		.0756		.111		102				
235	.0875		.0798		.123		113				
236	.0825		.0769		.115		106				
237	.0791		.0741		.113		104				
238	.0804		.0741		.114		105				
239	.0808		.0769		.122		112				
240	.0819		.0720		.110		101				
241	.0821		.0783		.124		114				
242	.0870		.0803		.122		112				
243	.0881		.0807		.121		111				
244	.0790		.0743		.114		105				
245	.0824		.0775		.124		114				
246	.0826		.0752		.115		106				
247	.0815		.0734		.116		107				
248	.0784		.0722		.114		105				
249	.0850		.0781		.121		111				
250	.0785		.0751		.118		109				
DATE	11-15		11-16				11-26				
STATION	H0-01		H0-01				Bench				
INSP. STAMP						Page 3-44					

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA
TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
251	.0832		.0791		.120		110				
252	.0816		.0746		.117		108				
253	.0754		.0694		.109		100				
254	.0921		.0872		.135		124				
255	.0783		.0737		.115		106				
256	.0861		.0805		.121		111				
257	.0784		.0732		.112		103				
258	.0821		.0775		.123		113				
259	.0836		.0781		.118		109				
260	.0842		.0822		.123		113				
261	.0774		.0716		.112		103				
262	.0857		.0779		.123		113				
263	.0824		.0752		.122		112				
264	.0803		.0740		.117		108				
265	.0769		.0726		.112		103				
266	.0831		.0773		.118		109				
267	.0821		.0741		.122		112				
268	.0801		.0756		.113		104				
269	.0790		.0746		.118		109				
270	.0835		.0783		.118		109				
271	1.18		1.10		.163		150				
272	.0772		.0713		.107		98				
273	.0825		.0783		.123		113				
274	.0817		.0790		.118		109				
275	.0824		.0769		.115		106				
DATE	11-15		11-16				11-26				
STATION	H0-01		H0-01				Bench				
INSP. STAMP											

REMARKS

NAME

TITLE

DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
276	.0826		.0772								
277	.0796		.0740								
278	.0811		.0740								
279	.0851		.0777								
280	.0971		.0902								
281	.0838		.0779								
282	.0787		.0723								
283	.0815		.0763								
284	.0831		.0761								
285	.0690		.0608								
286	.0687		.0644								
287	.0847		.0793								
288	.0767		.0741								
289	.0843		.0803								
290	.0796		.0733								
291	.0785		.0734								
292	.0798		.0746								
293	.0770		.0705								
294	.0829		.0802								
295	.0833		.0750								
296	.0829		.0786								
297	.0909		.0827								
298	.0833		.0766								
299	.0903		.0848								
300	.0778		.0724								
DATE	11-15		11-16								
STATION	H0-01		H0-01								
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
301	.0823		.0789								
302	.0817		.0729								
303	.0846		.0796								
304	.0856		.0763								
305	.0788		.0718								
306	.0828		.0751								
307	.0818		.0757								
308	.0817		.0771								
309	.0835		.0776								
310	.0815		.0749								
311	.0891		.0808								
312	.0831		.0790								
313	.0815		.0741								
314	.0780		.0734								
315	.0801		.0750								
316	.0801		.0748								
317	.0806		.0758								
318	.0811		.0771								
319	.0772		.0721								
320	.0847		.0789								
321	.0645		.0588								
322	.0918		.0862								
323	.0797		.0744								
324	.0926		.0834								
325	.0827		.0774								
DATE	11-15		11-15								
STATION	110-01		110-01								
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
326	.0771		.0745		.113		104				
327	.0939		.0860		.131		121				
328	.0743		.0717		.109		100				
329	.0823		.0771		.113		104				
330	.0734		.0702		.107		98				
331	.0793		.0739		-----		---				
332	.0768		.0704		.111		102				
333	.0829		.0753		.114		105				
334	.0819		.0759		.120		110				
335	.0866		.0802		.117		108				
336	.0789		.0723		.113		104				
337	.0839		.0753		.117		108				
338	.0823		.0779		.117		108				
339	.0935		.0868		.128		118				
340	.0736		.0674		.107		98				
341	.0819		.0747		.113		104				
342	.0797		.0732		.111		102				
343	.0855		.0772		.118		109				
344	.0794		.0747		.116		107				
345	.0833		.0749		.121		111				
346	.0775		.0729		.113		104				
347	.0779		.0739		.116		107				
348	.0815		.0736		.115		106				
349	.0841		.0763		.118		109				
350	.0833		.0757		.114		105				
DATE	11-15		11-15				11-26				
STATION	H0-01		H0-01				Bench				
INSP. STAMP						Page 3-48					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)

TABLE 3.14 (Cont'd)

GROUP REY098 SUBGROUP Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
351	.0812		.0727		.115		106				
352	.0837		.0781		.121		111				
353	.0792		.0724		.115		106				
354	.0646		.0600		.097		89				
355	.0875		.0815		.121		111				
356	.0812		.0732		.116		107				
357	10.7		10.8		----		---				
358	.0824		.0759		.112		103				
359	.0812		.0767		.111		112				
360	.0899		.0852		.130		120				
361	.0818		.0773		.124		114				
362	.0834		.0783		.116		107				
363	.0822		.0767		.118		109				
364	.0807		.0740		.117		108				
365	.0766		.0696		.112		103				
366	.0873		.0794		.118		109				
367	.0768		.0711		.108		99				
368	.0815		.0792		.115		106				
369	.0744		.0698		.109		100				
370	.0810		.0768		.116		107				
371	.0785		.0726		.114		105				
372	.0791		.0729		.116		107				
373	.0756		.0719		.117		108				
374	.0749		.0703		.113		104				
375	.0777		.0740		.116		107				
DATE	11-15		11-16				11-26				
STATION	HO-01		HO-01				Bench				
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.14 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP Initial θJ-C

UNIT							
MINIMUM							
MAXIMUM							
376	.0834		.0770		.121		111
377	.0817		.0748		.112		103
378	.0811		.0731		.117		108
379	.0825		.0758		.121		111
380	.0681		.0639		.107		98
381	.0835		.0745		.118		109
382	.0799		.0746		.121		111
383	.0832		.0763		.120		110
384	.0791		.0734		.110		101
385	.0842		.0779		.114		105
386	.0819		.0757		.115		106
387	.0841		.0763		.117		108
388	.0828		.0770		-----		---
DATE							
STATION							
INSP. STAMP							

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.15

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial θJ-C

Retest of initial θJ-C on HO-01* after scale change to correlate with Bench test

DIAL: 1.02
IC : 42mA
VCE : 500mw

S/N	θJ-C at 500mw
UNIT	°c/w
MINIMUM	
MAXIMUM	
1	106
2	112
3	114
4	111
5	100
6	188
7	114
8	120
9	108
10	112
11	115
12	114
13	104
14	111
15	106
16	123
17	114
18	112
19	108
20	109
21	---
22	109
23	117
24	120
25	114
DATE	12-4
STATION	HO-01
INSP. STAMP	

REMARKS (*) 2mA sense current used.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.15 (cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial
OJ-C

UNIT											
MINIMUM											
MAXIMUM											
26	115										
27	112										
28	114										
29	113										
30	109										
31	112										
32	113										
33	---										
34	110										
35	105										
36	109										
37	112										
38	129										
39	114										
40	115										
41	107										
42	108										
43	108										
44	---										
45	118										
46	136										
47	113										
48	112										
49	100										
50	---										
DATE	12-4										
STATION	HO-01										
INSP. STAMP						Page 3-52					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.15 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL5-05)
GROUP REY 098 SUBGROUP Retest-Initial

θJ-C

UNIT											
MINIMUM											
MAXIMUM											
51	115										
52	112										
53	111										
54	111										
55	109										
56	111										
57	129										
58	108										
59	104										
60	107										
61	114										
62	104										
63	116										
64	117										
65	127										
66	115										
67	128										
DATE	12-4										
STATION	H0-01										
INSP. STAMP						Page 3-53					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.16

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial θJ-C

Retest of Initial θJ-C Data on H0-01 after scale change to correlate with Bench Test.

Data taken on 1st 25 units on 12-6 & 12-16 for preliminary repeatability data for H0-01.

DIAL:	1.02		1.02		1.02						
IC :	42mA		42mA		42mA						
VCE :	11.9V		11.9V		11.9V						
S/N	θJ-C at 500mw		θJ-C at 500mw		θJ-C at 500mw						
UNIT	°c/w		°c/w		°c/w						
MINIMUM											
MAXIMUM											
101	---		---								
102	---		---								
103	117		116								
104	116		114								
105	120		119		120						
106	123		123								
107	120		118								
108	114		113								
109	109		107		107						
110	---		---								
111	129		127		127						
112	115		113								
113	134		133		129						
114	117		116								
115	111		112								
116	109		109		108						
117	121		119								
118	121		119								
119	114		113								
120	133		131								
121	114		112								
122	118		117		115						
123	123		120								
124	105		103								
125	117		116								
DATE	12-4		12-6		12-16						
STATION	H0-01		H0-01		H0-01						
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)

GROUP REY 098 SUBGROUP Retest-Initial

θJ-C

UNIT											
MINIMUM											
MAXIMUM											
126	115										
127	113										
128	186										
129	117										
130	115										
131	116										
132	134										
133	117										
134	118										
135	116										
136	122										
137	114										
138	120										
139	117										
140	107										
141	116										
142	127										
143	143										
144	118										
145	120										
146	115										
147	113										
148	122										
149	377										
150	120										
DATE	12-4										
STATION	110-01										
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial

θJ-C

UNIT											
MINIMUM											
MAXIMUM											
151	119										
152	114										
153	114										
154	112										
155	108										
156	115										
157	109										
158	114										
159	125										
160	119										
161	111										
162	119										
163	129										
164	102										
165	122										
166	115										
167	109										
168	118										
169	121										
170	124										
171	114										
172	122										
173	115										
174	115										
175	115										
DATE	12-4										
STATION	HO-01										
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)

GROUP REY 098 SUBGROUP Retest-Initial θJ-C

UNIT											
MINIMUM											
MAXIMUM											
176	121										
177	123										
178	128										
179	122										
180	114										
181	116										
182	120										
183	110										
184	118										
185	111										
186	111										
187	121										
188	113										
189	122										
190	114										
191	116										
192	113										
193	115										
194	121										
195	121										
196	111										
197	114										
198	112										
199	119										
200	109										
DATE	12-6										
STATION	HO-01										
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial

θJ-C

UNIT											
MINIMUM											
MAXIMUM											
201	114										
202	122										
203	108										
204	119										
205	118										
206	122										
207	115										
208	150										
209	113										
210	113										
211	128										
212	111										
213	123										
214	115										
215	111										
216	98										
217	127										
218	108										
219	116										
220	114										
221	125										
222	117										
223	120										
224	116										
225	110										
DATE	12-6										
STATION	110-01										
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER (SL3-05) 544
GROUP REY 098 SUBGROUP Retest-Initial

θJ-C

Data taken on 12-6 on S/N 226 through 275 was to observe the effect of removing the CAP on θJ-C.

			CAP OFF								
UNIT											
MINIMUM											
MAXIMUM											
226	115		114								
227	117		117								
228	103		105								
229	118		114								
230	91		89								
231	108		107								
232	136		135								
233	118		115								
234	115		115								
235	121		120								
236	115		114								
237	116		114								
238	114		112								
239	117		116								
240	111		111								
241	119		118								
242	121		121								
243	124		123								
244	111		112								
245	115		114								
246	114		113								
247	113		115								
248	110		108								
249	117		117								
250	113		111								
DATE	12-4		12-6								
STATION	H0-01		H0-01								
INSP. STAMP						Page 3-59					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial

θJ-C

			CAP OFF								
UNIT											
MINIMUM											
MAXIMUM											
251	120		119								
252	114		112								
253	105		104								
254	115		---								
255	115		112								
256	123		120								
257	110		108								
258	118		117								
259	119		117								
260	124		122								
261	112		109								
262	123		121								
263	117		116								
264	116		113								
265	108		108								
266	117		114								
267	116		114								
268	113		112								
269	111		108								
270	116		118								
271	167		165								
272	111		110								
273	120		118								
274	116		115								
275	117		114								
DATE	12-4		12-6								
STATION	110-01		110-01								
INSP. STAMP						Page 3-60					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial

θJ-C

UNIT											
MINIMUM											
MAXIMUM											
306	116										
307	115										
308	117										
309	119										
310	114										
311	123										
312	120										
313	112										
314	110										
315	113										
316	113										
317	112										
318	120										
319	109										
320	119										
321	92										
322	131										
323	114										
324	126										
325	116										
326	116										
327	134										
328	109										
329	116										
330	108										
DATE	12-6										
STATION	H0-01										
INSP. STAMP						Page 3-61					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 3.61 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial

θJ-C

UNIT											
MINIMUM											
MAXIMUM											
331	---										
332	107										
333	115										
334	117										
335	122										
336	109										
337	115										
338	118										
339	134										
340	108										
341	115										
342	115										
343	120										
344	111										
345	116										
346	107										
347	111										
348	115										
349	115										
350	117										
351	113										
352	120										
353	113										
354	92										
355	125										
DATE	12-6										
STATION	110-01										
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JRL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial
θJ-C

UNIT											
MINIMUM											
MAXIMUM											
356	113										
357	---										
358	116										
359	115										
360	131										
361	117										
362	118										
363	118										
364	---										
365	111										
366	119										
367	110										
368	120										
369	111										
370	116										
371	114										
372	116										
373	109										
374	104										
375	115										
376	117										
377	113										
378	117										
379	116										
380	98										
DATE	12-6										
STATION	H0-01										
INSP. STAMP						Page 3-63					

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 3.16 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Retest-Initial

UNIT	
MINIMUM	
MAXIMUM	
381	115
382	114
383	116
384	112
385	119
386	116
387	120
388	---
DATE	12-6
STATION	H0-01
INSP. STAMP	

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

4.0 PHASE II TESTS
θJ-C MEASUREMENT ACCURACY AND REPEATABILITY

4.1 Experimentation and Modification of Original Test Program

The original test plan was to use two hundred and ten devices randomly selected and divided into four groups. Group 1 would contain 25 units for the thermocouple experiment, Group 2 would contain 30 units for the infrared experiment, Group 3 would contain 55 units for the temperature paint experiment, and Group 4 would contain 100 units for the repeatability experiment. Certain technical problems were encountered and some modifications were made in this portion of the program. The modifications did not alter the scope or effort originally planned for meeting the contract requirements. The next five paragraphs describe the tests as they were actually performed.

4.1.1 Thermocouple Method

It was originally planned to stitch bond a 1 mil chromel-alumel thermocouple to the emitter area on 25 devices. When the bonding was started, only one successful bond was achieved after five hours of effort and four destroyed transistors. The junction on the end of the 1 mil thermocouple was approximately 3 mils in diameter. When subjected to stitch bonding, this junction flattened out enough to produce a base-emitter short. It was decided, therefore, to bond the thermocouples with a special "HT" cement manufactured by Omega specifically for bonding thermocouples to surfaces to be operated at high temperatures. This also proved to be a difficult operation. The 1 mil thermocouple had to be formed to prevent shorting base to emitter, placed on top of the emitter wire bond attached to the die, and a drop of HT cement applied, all under a microscope. Extreme care was taken to prevent breaking the 1 mil wires. Because of the length of time required to bond the thermocouples with HT cement and the extremely fragile nature of the 1 mil wires, the quantity of thermocouples to be bonded was changed from 25 to 11. One was stitch bonded and ten were bonded with HT cement. The number of scheduled readouts on each device was increased from one to four to partially compensate for reduced sample size.

Two additional problems were introduced with the new bonding method. The θJ-C values were found to be lowered approximately 10% by the application of HT cement, the actual percentage depending on the amount of cement used (see Page 1 of Table 4.3). Consequently, all devices were remeasured on θJ-C after the thermocouples were bonded. Second, the thermal time constant of the device was increased significantly so that even though the 1 mil thermocouples had a thermal time constant of approximately 50 milliseconds, the blob of HT cement holding the thermocouple raised the overall time constant to many seconds. This prevented using this method to determine the maximum junction temperature reached during a one second power pulse as had been originally proposed. An alternate plan was chosen to determine the steady state maximum operating junction temperature using the bench tester to measure ΔVBE (from which ΔTJ was calculated) and the 1 mil thermocouple to measure ΔTJ directly. The 500mW power level was used since it was established during the initial correlation tests (described in

Section 3.1) that $\theta J-C$ was independent of power level. Also, the original assumption that $\theta J-C$ would be higher when the cap was removed was found to be in error. The value of $\theta J-C$ was found to be independent of the cap being on or off (see Table 3.16 in Section 3.5 and Table 4.1 in 4.2). Some additional information obtained from this experiment that was not originally planned was data for calculating $\theta C-A$ for devices operated in still ambient air with caps removed. The data was used as a basis for the temperature-indicating paint tests described in Section 4.4.

4.1.2 Infrared Microscope Method

The first change in this test plan was the elimination of the five devices for determining emissivity. In discussing arrangements for this test with Autonetics (infrared microscope facilities at Autonetics were used for this experiment), it was determined that the test procedure to be followed would automatically account for emissivity and that a separate measurement would not be necessary. The second change in the test program was to reduce the number of samples for infrared scanning from 25 to 5. This was necessary because of the amount of time required (almost two days for five devices) for accurately scanning each device. The experiment to determine the maximum junction temperature reached during a 1 second power pulse was not performed due to the limited time available on the Autonetics equipment. In addition, the power levels used were 250mW, 500mW, and 750mW rather than the original values of 500mW, 750mW, and 1083mW due to difficulties encountered in working at the higher junction temperatures with the Philco Thermal Plotter during temperature calibration tests (see Section 4.3).

4.1.3 Temperature-Indicating Paint Method

The test program for this experiment was modified in several ways. Tests A, B, and C (see Figure 1) were performed with steady-state power applied to units in moving 100°C air corresponding to the proposed JPL Accelerated Test Program rather than the 1 second power pulse in still ambient air originally proposed. It was found that the temperature-indicating paint had a slow thermal response time (from seconds to minutes, depending on temperature range) and could not be used to accurately determine temperature changes during a 1 second power pulse. As a result, the steady-state-type operation was necessary. The power level to be used was calculated individually for each device based on its measured $\theta J\text{-}C$ and the mean value of $\theta C\text{-}A$ determined from the tests of Section 5.3. Power levels selected were to cover junction temperature values between 175°C and 335°C and case temperature values from 120°C to 230°C, which corresponded to the temperature range of Detecto-Temp paint types available. The 25 units originally scheduled for test group G were divided into three groups (G01, G02, and G03) and Detecto-Temp paints with those temperature ranges between 60°C and 155°C were applied. Power was applied to each device while observing it under a microscope. The power level was increased in small steps until the paint changed color, indicating that a specific temperature had been reached. The value of power required to reach that temperature was recorded. An additional group of thirty devices was added to the program as tests K, L, and M. These tests were performed in a similar manner to those of G01, G02, and G03, except the paint temperature range was from 120°C to 340°C. Also, the value of $\theta J\text{-}C$ was affected by the amount of Detecto-Temp paint applied. It was necessary, therefore, to remeasure

θJ-C on all devices on tester HO-01 (1 second power pulse) after the paint had been applied. Due to the short duration of the power pulse, no change in the paint colors occurred during the remeasurement of θJ-C at the 500mW level.

4.1.4 Water Bath Method

Due to the poor results of the infrared microscope method, it was felt that one additional independent verification method should be included in the program. The water bath method was selected and although only one device was tested, the method was very precise and repeatable.

4.1.5 Repeatability Verification

The tester to be used for this experiment was HO-01. The modification of the tester to show adequate correlation with the bench tester took longer than previously planned. This prohibited using the tester over a sustained time period to perform the repeatability tests. Consequently, the repeatability test was performed during two eight-hour shifts.

4.2 Thermocouple Method

After it was determined that a 1 mil chromel-alumel thermocouple could not be readily stitch bonded to the emitter area, an evaluation of two bonding cements was performed to determine their suitability for this program (see Table 4.1). The two cements evaluated were Omega "HT" and Eastman 910. A very small amount of each cement was applied to the die on three 2N2222 devices that had been previously measured on θJ-C using tester HO-01, both before and after their caps were removed. The removal of the caps had negligible effect on the value of θJ-C. The Omega HT cement showed no significant effect on θJ-C in the wet or dry state. The Eastman 910 cement showed considerable effect of reducing θJ-C while wet and shorting out the device when dry. The Omega HT cement was selected for the bonding of thermocouples to the emitter area of test devices used for this experiment.

Twenty five devices that had previous θJ-C measurements on tester HO-01 were selected for this test (Group F01). The θJ-C values chosen were representative of the broad distribution of the entire test lot of 2N2222 devices (production lot 544, process SL3-05). The caps were removed from the 25 test units and an attempt was made to stitch bond a 1 mil chromel-alumel thermocouple to the emitter area of each device. As previously mentioned in Section 4.1, only one device was successfully stitch bonded. An additional group of ten devices were suitably bonded with the Omega HT cement. During the initial evaluation of HT cement, no significant effect on θJ-C was observed; however, when a much larger amount of cement was applied to adequately hold the thermocouples firmly on the die, a reduction in θJ-C of approximately 10% was found. All devices were then remeasured for θJ-C on tester HO-01. The original θJ-C values and post bonding values are shown on Page 1 of Table 4.3.

The eleven test devices were operated at 500mW in still ambient air and ΔVBE was measured with the bench tester and the

TJ was measured with the 1 mil thermocouples on a Honeywell Model 2733 potentiometer bridge that had been calibrated by the Motorola Temperature Standards Laboratory. Each individual device was measured from one to eight times, depending upon how long the 1 mil thermocouple wires survived the required handling. The ambient air temperature (TA) was measured with an expanded scale (.1°C/division) laboratory thermometer (TCA Model 444324), which was also calibrated by the Temperature Standards Laboratory. The test data is shown in Table 4.2. On the eighth readout, a 3 mil copper-constantan thermocouple was soldered to the index tab on the header flange of eight of the test devices for measuring case temperature. Only the 500mW power level was used for these tests since θJ-C had been shown to be independent of power level by the initial correlation tests described in Section 3.1. The ΔVBE measurements were converted to TJ values by using the "K" factor of -1.84mV/°C established during the initial correlation tests, and the measured value of TA. This data is shown on Pages 1 and 2 of Table 4.3 along with the calculated percentage difference (Δ%) between the value of junction temperature determined from ΔVBE (considered as the calculated value) and the value measured directly with a thermocouple. On the eighth readout, the case temperature was computed from the relationship shown in equation (3).

$$TC = TJ - \theta J\text{-}C \times P \tag{3}$$

where TC = Calculated Case Temp.
TJ = Calculated Junction Temp.
θJ-C = Measured Thermal Resistance
P = Power Dissipation

The calculated TJ was used in this computation rather than the measured value because in several instances, the 1 mil thermocouple had been broken and no value of measured TJ was available.

On Page 3 of Table 4.3, the mean values of measured and calculated TJ for each individual unit are presented. Since TC was measured on one readout, the mean measured value was the same as the eighth readout value. For the mean calculated value of TC, the computation was made using equation (3) and the mean value of calculated TJ.

The range of the observed difference between measured TJ and calculated TJ was +2.1% to -15.0% for individual readouts. For the individual device mean values, the range of the observed differences was +1.6 to -12.4% and overall mean value for all devices was -5.6%. It was noted that with only one exception (unit #245, which had only a single readout prior to damaging the 1 mil thermocouple), the ten devices bonded with HT cement had a negative difference, that is, the thermocouple indicated a lower junction temperature than that calculated from ΔVBE. We postulated that the thermocouples were not actually in physical contact with the junction surface. Several attempts were made to X-Ray the devices to resolve this question; however, the density of the HT cement was such that the 1 mil thermocouple could not be distinguished from the background. The postulation was verified by using a resistance bridge (ohmmeter) to determine if electrical continuity existed between the thermocouple and the emitter on each device. All ten devices with HT cement were found to be "open" that is, the thermocouples were not in intimate physical contact with the junction. Evidently, a thin film of HT cement was deposited under the thermocouple during the bonding operation. The device that was stitch bonded (Unit #276) had a mean difference between measured and calculated TJ of only +1.6%. It was also observed that the one other device that had a very low percentage difference (also positive) between measured and calculated TJ had shown a 2.6% decrease in θJ-C after bonding. This indicated that a much smaller amount of cement was used in bonding this device (confirmed by visual observation).

For a nominal θJ-C value of 100°C/W, an absolute accuracy of ±10% represents a ±6.7% TJ accuracy at 500mW and TC = 25°C (condition under which initial θJ-C would normally be measured). Since the observed mean error in TJ measurement by the thermocouple method was -5.6%, the accuracy of the ΔVBE measurement technique was verified. In fact, if the error caused by the cement under the thermocouple could be eliminated, this method would very likely have a mean error under ±3%.

The observed mean difference between measured and calculated values for TC was -9.7%. Some difficulty was initially experienced with the 3 mil copper-constantan thermocouples giving measured TC readings that were considerably lower than the values shown on Page 2 of Table 4.3. The thermocouples had originally been bonded to the index tab of the header flange with Eastman 910 cement. Evidently, the cement flowed under the thermocouple during the "curing" period and formed an insulating layer. The thermocouples were removed and soldered on for the balance of the tests.

The relatively large temperature difference observed with the thermocouples soldered on was considered to be due to the location of the thermocouples. Observations made during the temperature-indicating paint tests (Section 4.4) showed a considerable temperature gradient between the point on the header where the die was mounted and the edges of the header.

Values of θJ-A and θC-A were computed for each device from the mean values of TJ, TC, and TA. These calculated values are presented on Page 3 of Table 4.3. Analysis of data indicated that units #236 and #239 had a measurement error during the experiment and these devices were not considered in determining the final mean values (Mean "B" in Table 4.3). Also, since the stitch-bonded device, unit #276, was physically different from the others in that it did not have the drop of HT cement on the junction surface and header area, it was not considered in calculating the final mean values. The final mean value of θC-A, computed from the calculated values of TC, was found to be 262°C/W. This value was used for calculating θJ-A values for the temperature-indicating paint tests of Section 4.4.

4.3 Infrared Microscope Method

This experiment was performed at the Autonetics Division of North American Aviation in Anaheim, California, where a Philco Thermal Plotter infrared (I/R) microscope facility was made available to Motorola. Specifications for the Philco instrument used are presented in the Appendix of this report.

The procedure consisted of inserting an individual device in the Motorola test fixture after it had been mechanically modified and rigidly mounted on the viewing stage of the I/R microscope. Adjustments were made to align the device so that the mechanically indexed stage would permit scanning along a selected path on the emitter metallization pattern. A "no power" calibration run was made to set the horizontal axis scale factor for an X-Y recorder that was used as the I/R radiation readout device. Steady-state power of 250mW was applied to the test device and the stage was indexed so that the entire die was scanned. This run was necessary to determine the proper scale to use for the vertical axis (I/R radiation units). Power was removed and the vertical axis was calibrated with a standard calibrating voltage. The 250mW steady-state power was again applied and an X-Y plot was made of the I/R radiation level versus position on the die by mechanically scanning the die across the emitter pattern. The power level was then raised to 500mW and the procedure was repeated except for the device alignment step. Following the completion of the 500mW radiation scan, the power level was raised to 750mW and the procedure repeated once more. After the 750mW power level scan was completed, the device was removed from the test fixture, a new test device inserted, and the entire procedure repeated. This same procedure was followed for all devices tested. Originally, a power level of 1083mW was to be used; however, Autonetics suggested that considerable difficulty would be encountered in running temperature calibration tests at such high junction temperatures ($\approx$340°C), so this power level was not used.

Upon completion of the individual device radiation plots, the temperature calibration procedure was started. The Motorola test fixture was removed from the viewing stage of the microscope and a special metal fixture containing heating elements and an iron-constantan thermocouple was installed on the stage. The top plate of the fixture had three small holes to fit the lead configuration of the TO-18 package of the 2N2222 and permitted the header flange of each device to fit flat against the metal surface. After one of the test devices had been inserted, the fixture was oriented to permit scanning the same path that had been covered during the I/R radiation tests. Four specific radiation levels were selected from each individual device radiation plot to be used for temperature calibration. These four points represented two points of maximum radiation (one located in middle of base metallization area) and two points of minimum radiation level (one located on silicon area between base and emitter metallization and one in the center of the emitter wire bond) for a given fixed power dissipation. The center of the emitter wire bond was a minimum because the raised surface of the bond was out of focus for the I/R microscope which had been accurately focused on the base and emitter metallization. The temperature of the metal fixture was then raised by adjusting a Variac controlling the heating elements until the I/R radiation level at one of the four selected points was identical to that observed during the scanning of the device with power applied. The temperature value (determined from the iron-constantan thermocouple) was recorded. The entire die was then scanned and an X-Y plot made of the radiation levels at the elevated temperature condition. This procedure was repeated for the other three points and then the entire procedure was repeated for the other two power levels. The overall procedure described above was followed for each of the test devices.

The results of the temperature calibration tests were very poor. The calculated junction temperature should have correlated with the observed temperatures at the emitter metallization for a given device. For test unit #305, using θJ-A of 375°C/W (θJ-C of 113°C/W measured on tester HO-01 plus θC-A of 262°C/W determined from thermocouple method tests of Section 4.2) the calculated junction temperatures were 119°C at 250mW, 213°C at 500mW, and 306°C at 750mW. The temperatures determined from the calibration tests were, respectively, 106° ±10°C, 98° ±5°C, and 104° ±10°C. Similar results were obtained for the other test devices. The basic cause for the poor results was attributed to the difficulty in precise device alignment between the IR radiation tests and the temperature calibration tests on a given device. Due to the nature of the test fixtures used, it was necessary to change the devices from one fixture to the other to perform both tests and the alignment of the devices for scanning could not be identical. Autonetics had been successful on previous tests of other semiconductor devices (not in TO-18 packages) in getting good correlation (±10°C) between calculated and observed temperatures; however, the devices were scanned for I/R radiation level with power applied in the same special fixture used to perform the temperature calibration test so that an individual device was never moved once the scanning path was established. For the 2N2222 tests at the higher surface temperatures (>150°C), a special oil used by Autonetics to insure good thermal contact between the metal fixture (for temperature calibration tests) and the header flange of the test device, reached the "smoke" point and caused some difficulty in focusing.

4.4 Temperature-Indicating Paint Method

The first investigation made during this series of experiments was an evaluation of the Detecto-Temp temperature indicating paint that had been selected for use. This paint was manufactured and supplied by the H. V. Hardman Co.

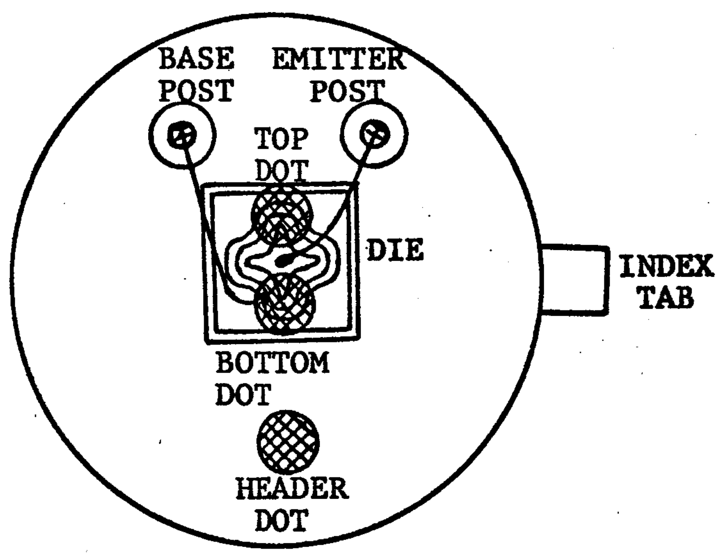
The paint evaluation consisted of placing ten dots of each of the sixteen types of paint selected in different locations on a silicon wafer one inch in diameter. The wafer surface contained the same aluminum metallization and geometric pattern as wafers used in the production fabrication of the 2N2222 device. The paint types and specified colors and color-change temperatures are shown in Table 4.4. An oven with precision temperature control (±1°C) was stabilized (monitored with copper-constantan thermocouple and Honeywell Model 2733 Potentiometer) at 40°C. This was 10°C below the specified color-change temperature of the lowest temperature paint to be evaluated. Following stabilization, a small port in the top of the oven was opened momentarily and the silicon wafer with the paint samples on its surface was lowered into the chamber on a teflon wire "sling" and the port was closed. The wafer remained in the oven for five minutes and was removed. The colors were examined under a 10 power microscope for any indication of color change. This procedure was repeated in 5°C steps (except for the temperature ranges for which no paint was being evaluated) up to the maximum value of 350°C. The results of the evaluation are shown in Table 4.4.

Although only six of the sixteen Detecto-Temp paint types evaluated met the manufacturers specification, ten of the types had color-change temperatures that were satisfactory for use. In Table 4.4, where two temperatures are shown in the same column for the same paint (for example, paint type 915 - 902), a portion of the ten color dots changed at the lower temperature and the remaining ones changed at the higher value.

The effect on θJ-C of applying Detecto-Temp paint to the junction surface of the 2N2222 device was also evaluated. Three units (caps removed) were measured for θJ-C on tester HO-01. The three devices were coated with Detecto-Temp paint. Unit #385 received a thin coating, unit #386 received a medium coating, and unit #387 was given a thick coating. The devices were remeasured on HO-01 immediately after the paint was applied and again after the paint was thoroughly dry. The data, shown in Table 4.1 of Section 4.2, indicated that the effect on θJ-C depended upon the thickness of the applied coating. It was decided that all devices would be remeasured on θJ-C after application of the paint so that initial values of θJ-C would be correct. Since tester HO-01 applied only a 1 second power pulse, there would be no danger of the paint color changing during remeasurement of θJ-C (see Section 4.1.3).

For the measurement of junction and header temperature tests, the temperature-indicating paint was applied to the junction and header areas as shown in Figure 6. The paint dots were applied in this manner under a 10 power microscope. Due to the quick drying characteristic of the paint (ethyl alcohol vehicle), it was very difficult to get uniform paint dots on all test devices. Some of the dots covered a considerable area on the die and/or header.

TOP VIEW
2N2222 TO-18 HEADER
(CAP REMOVED)



DETECTO-TEMP PAINT DOT LAYOUT FOR POWER LEVEL TESTS

Figure 6

The power levels calculated to raise the junction to the color-change temperatures of the selected paint dots were computed from the individual values of $\theta J\text{-}A$ for each device and the measured ambient temperature. The value of $\theta J\text{-}A$ was obtained by adding 262°C/W, the mean value of $\theta C\text{-}A$ determined from the thermocouple method experiments of Section 4.1, to the measured value of $\theta J\text{-}C$. The calculated power level to raise the header to the color-change temperature was computed from the value of $\theta C\text{-}A$, 262°C/W, and the ambient temperature.

For tests G01, G02, G03, K01, L01, and M01, (see Figure 1), the individual test devices were observed under a Spencer 10-40 power microscope while power was applied. The power level was started at approximately 50% below the calculated value and increased gradually in small steps until the desired color-change was observed. The power was applied through the bench tester test circuit and the temperature was allowed to stabilize for at least two minutes at each power step. The power level at which the color change occurred was recorded. The results are given in Tables 4.5 and 4.6. Comparisons between the calculated power levels and the observed power levels required to reach specific junction and header temperatures are shown in Table 4.8. The error for individual devices showed considerable range with values from as low as 0.4% to as high as 30.1%. The mean error for a given group of devices with the same paint types varied between 5.5% and 20.1%, while the overall mean error was 10.4% for junction temperature power levels and 11.1% for header temperature power levels. Although the individual errors were both positive and negative, almost 70% of the errors were in the positive direction. This would indicate that the calculated power level was generally greater than the observed value. Since the value of θC-A used for the calculated power levels was computed from data on devices that had HT cement on their junctions (although all other conditions were the same as on this experiment), the value of θC-A for devices with only Detecto-Temp paint on their junctions may have been somewhat higher. This would have reduced the power levels of the calculated values. Also, some of the color changes were not very pronounced, and the decision as to the power level at which the change actually occurred was sometimes very difficult. Generally, it was felt that this portion of the experiment was only suitable for a good approximation of the power level required to reach a specific junction or header temperature and that it was not adequate for verification of the absolute accuracy of the thermal resistance measurements.

It was noted during the experiment that in many cases, the color dot on the header would start changing color where the paint was near the die at power levels from 5% to 25% lower than the level required for the majority of the color dot to change. This would indicate that a temperature gradient of from 5°C to 25°C could exist between a point on the header very near the die and a point on the edge of the header.

The last portion of the temperature-indicating paint investigation method consisted of tests A01, B01, and C01 (see Figure 1). For this experiment, the thirty test devices chosen were unwelded units. Their θJ-C values were measured on tester HO-01. Detecto-Temp paint was applied in the same manner as for the other experiments (see Figure 6). θJ-C was again measured on tester HO-01 and the devices had their caps welded on in a special welding procedure so that the units were not exposed to any temperature greater than 110°C. After weld, the test devices were again tested for θJ-C on tester HO-01. To these final values of θJ-C, a θC-A value of 110°C/W was added to calculate the individual device values of θJ-A. The value of θC-A (110°C/W) was obtained from the θC-A measurement tests of Section 5.3. This value was for operation of a TO-18 case (cap on) in moving 100°C air. Using the individual values of θJ-A, the power level required to reach a temperature half way between the color-change temperatures of the top and bottom color dots (Figure 6) was computed. The devices were then placed in an oven with moving air at 100°C and the calculated power applied to each device for a period of two minutes. The devices were then removed from the oven, allowed to cool to room ambient temperature, and their caps were removed. Each device was then examined carefully under a Spencer 10-40 power microscope to determine what color changes had occurred. The results of these three experiments are shown in Table 4.7.

For test A01, the calculated power levels were all correct in that all the top color dots (170°C) changed, and none of the bottom color dots (180°C). This would mean that the calculated power level gave the correct TJ of 175°C within ±5°C (±2.9%). The power level applied was high enough (>182mW) on each device so that the 120°C color dot on the header should have also changed. However, in no instance did it change. The only explanation was that a higher temperature paint had mistakenly been applied to the header (many of the paints used had similar colors at room temperature). This was further indicated when the header dots on the other tests changed as predicted.

In test B01, eight of the nine devices tested showed correct calculated power levels with the top color dots (230°C) changing and the bottom dots (240°C) not changing. This indicated that the calculated power level gave the correct TJ of 235°C within $\pm$5°C ($\pm$2.1%). Neither the top nor the bottom dot changed in the remaining device (unit #16) so no value could be placed on the accuracy of the junction temperature reached. It could have been anywhere from approximately 210°C (-8.7%) to 220°C (-0.4%). The value of 210°C was calculated from θJ-C and the 572mW applied (yielded ΔTJ from junction to case) added to the minimum header temperature (TC) of 140°C. This minimum header temperature was established because the header color dot (140°C) changed on all nine devices.

For test C01, both the top color dots (330°C) and the bottom color dots (340°C) changed. This would indicate that the TJ values were at least 5°C greater than predicted. Careful examination of the color dots indicated that although the bottom dots had started changing, only one of the ten devices tested had reached the full brown-gray color, indicating 340°C or greater. The remaining dots were either brown and light gray or similar shades, indicating that the junction had not quite reached 340°C. Therefore, the calculated power level for nine of the ten devices yielded TJ values of 335°C $\pm$5°C ($\pm$1.5%) and the remaining device was >340°C. On the basis of the other nine devices being within approximately 1°C or 2°C of 340°C, judging from colors observed, it is very likely that the other device (unit #26) did not exceed 346°C (+3.0% from 335°C). The header dots (230°C) changed color from green to light green and light brown. This indicated that the

220°C level had been exceeded, but not the 225°C level. (see Table 4.4 for Detecto-Temp paint type 915-908). For the power levels applied (from 1025mW to 1090mW), the calculated case temperatures were between 213°C and 220°C. Therefore, the case temperatures were within 12°C (5.6%) or less of the predicted value.

The results of this last part of the temperature-indicating paint method experiments were suitably accurate so as to constitute verification that the absolute measurement accuracy of θJ-C is well within the program objective of ±10%.

4.5 Water Bath Method

The measurement procedure for the water bath method was similar to that used in the thermoelectric cooler experiment described in Section 3.1 (Table 3.4). The test device was immersed in circulating deionized water at room ambient temperature with two milliamperes of sense current applied through the circuit of the bench tester. VBE was measured with a Hewlett-Packard Model 412-A VTVM and also observed on a Tektronix Model 561A CRO with a Model 2A63 differential amplifier input unit. The case temperature (essentially the same as the water temperature with only sense current flowing) was measured with a calibrated expanded scale (.1°C/division) laboratory thermometer. 500mW of power was then applied to test device and the change in the VBE (ΔVBE) was measured on the CRO. Power was removed from the device (except for the 2mA sense current) and VBE was allowed to return to its original value. The temperature of the circulating water bath was then raised (using an electric hot plate) slowly until the change in VBE (ΔVBE) measured on the VTVM and CRO was identical to that observed with 500mW of power applied. The temperature of the hot water bath was measured with the laboratory thermometer. The data obtained from these series of measurements is shown in Table 4.9.

θJ-C was first calculated by dividing the 113mV ΔVBE value by the "K" factor, -1.83mV/°C (which converted ΔVBE to ΔTJ), and by the power level of 0.5 watt. The value calculated was 122.8°C/W. θJ-C was then calculated by subtracting the ambient water temperature from the hot water temperature (which yielded ΔTC = ΔTJ at "0" power) and dividing the difference by the 0.5 watt power level. This value of θJ-C was found to be 124.8°C/W. These calculated values are presented in Table 4.10. The percent error between the bench tester and the water bath method was only 1.6%. Since the water bath method did not involve any attachments to or modifications of the device under test (such as removing cap, bonding thermocouples, applying paint, etc.) and because the parameters involved (VBE at 2mA and water temperature) were easily measured with a high degree of accuracy ($\pm$1mV on VBE and $\pm$0.1°C on temperature), the technique was very precise. Therefore, the 1.6% error observed between the bench tester θJ-C and the value obtained by the water bath method was verification that the absolute accuracy of the bench tester was well within the $\pm$10% objective of the program.

4.6 Repeatability Verification

All of the transistors to be used in the JPL Accelerated Life Test Program (RFP No. 0541) will be measured for thermal impedance prior to stress testing. The accuracy of measurement required is $\pm 10\%$ and the repeatability must be $\pm 5\%$ or better.

For this test group (E01) 100 units were randomly selected from the 288 test devices and serialized 126 through 225 exclusively. The experiment was set up so that each device would be measured consecutively on θJ-C using the Motorola HO-01 tester. Following the 100 consecutive unit readings denoted as the first run, the procedure was repeated nine times so that ten readings on each device would be obtained. This data is presented in Table 4.11. Best results are obtained if the parameter measured has values in the low, middle, and high portions of the range of the population range of that parameter. It is observed from Table 4.11 that the minimum θJ-C was 96.5°C/W and the maximum value was 144°C/W, which represented a spread of 49.2% from the lowest to highest value. This was excellent for determining an accurate estimate of the repeatability of the tester.

To determine the variation among the various readings and to provide an estimate of the repeatability of the thermal impedance tester, the coefficient of variation was calculated on each unit, using the following formula:

$$C.V. = \frac{\sqrt{\dfrac{n \sum_{i=1}^{n} (X_i)^2 - (\sum_{i=1}^{n} X_1)^2}{n(n-1)}}}{\sum_{i=1}^{n} X_i} \times 100$$

where the X_i values are individual θJ-C measurements on a device and n is the number of consecutive times each unit was measured.

The results are tabulated in Table 4.11 in the last column denoted by C.V. This data shows a maximum value of 2.188% which was obtained on unit #139. The value of 121°C/W for θJ-C measured on this unit the first time is in the middle of the range of values obtained on θJ-C for the 100 units.

The average C.V. for the 100 units is 1.26%. We conclude from this experiment that the Motorola tester HO-01 meets the ±5% repeatability requirement in the JPL Accelerated Test Program Specification.

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 4.1

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP F01

Evaluation of proposed thermocouple bonding agents applied to junction area.

DIAL:1.020 IC :42mA VCE :11.9V	CAP ON	CAP OFF		Omega Ht Cement WEY	 DRY		Eastman 910 cement WET	 DRY		Detecto Temp Paint WET	 DRY
	θJ-C at 500mw	θJ-C at 500mw		θJ-C at 500mw	θJ-C at 500mw		θJ-C at 500mw	θJ-C at 500mw		θJ-C at 500mw	θJ-C at 500mw
UNIT	°c/w	°c/w		°c/w	°c/w		°c/w	°c/w		°c/w	°c/w
MINIMUM											
MAXIMUM											
379	115	113		114	116						
380	99	96		95	95						
381	115	114		115	115						
382	115	114					104	Short			
383	117	117					111	Short			
384	111	111					Open	Open			
385	119	115								119	117
386	115	115								112	112
387	120	119								108	108
DATE	12-4	12-4		12-4	12-4		12-4	12-4		12-4	12-4
STATION	H0-01	H0-01		H0-01	H0-01		H0-01	H0-01		H0-01	H0-01
INSP. STAMP						Page 4-26					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)

TABLE 4.2

GROUP REY 098 SUBGROUP F01

Measurement of Junction Temperature (TJ) at 500mw* in still ambient air (TA)
CAP OFF 1 Mil Chromel-Alumel thermocouple bonded to emitter area with Omega HT Cement

S/N	1st Readout ΔVBE at 500mw	1st Readout TA	1st Readout TJ at 500mw	2nd Readout ΔVBE at 500mw	2nd Readout TA	2nd Readout TJ at 500mw	2nd Readout ΔTJ at Null	3rd Readout ΔVBE at 500mw	3rd Readout TA	3rd Readout TJ at 500mw	3rd Readout ΔTJ at Null
UNIT	mv	°C	°C	mv	°C	°C	°C	mv	°C	°C	°C
MINIMUM											
MAXIMUM											
236	299	25.3	175.8	312	25.2	179.7	+9.3	295	24.7	168.2	+8.3°
239	268	24.6	166.4	272	25.3	161.1	+8.0	---	---	---	---
240	---	---	---	---	---	---	---	---	---	---	---
242	---	---	---	314	25.2	196.7	+9.5	310	24.6	195.1	+9.5
243	---	---	---	320	24.8	194.6	+10.3	319	24.6	196.1	+9.8
244	---	---	---	327	25.0	199.0	+10.3	318	24.6	193.9	+9.0
245	---	---	---	---	---	---	---	314	24.7	205.0	+8.3
246	---	---	---	---	---	---	---	---	---	---	---
247	---	---	---	---	---	---	---	---	---	---	---
250	---	---	---	---	---	---	---	326	24.7	189.5	+9.5
276**	---	---	---	---	---	---	---	---	---	---	---
DATE	12-9			12-11				12-13			
STATION	Bench			Bench				Bench			
INSP. STAMP											

REMARKS (*) IC=40mA, VCE=12.5V
(**) 1 Mil Chromel-Alumel thermocouple stitch bonded to emitter area.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)

TABLE 4.2
(Con't)

GROUP REY 098 SUBGROUP F01

	4th Readout			5th Readout				6th Readout			
S/N	ΔVBE at 500mw	TA	TJ at 500mw		ΔVBE at 500mw	TA	TJ at 500mw		ΔVBE at 500mw	TA	TJ at 500mw
UNIT											
MINIMUM											
MAXIMUM											
236	300	25.3	169.3		300	25.1	167.1		330	25.2	183.2
239	---	---	---		---	---	---		---	---	---
240	310	25.3	189.3		305	25.1	189.9		313	25.2	---
242	323	25.3	195.6		338	25.2	204.0		---	---	---
243	338	25.3	196.5		331	25.2	191.7		341	25.2	191.2
244	327	25.1	196.6		337	25.2	198.5		338	25.2	191.7
245	---	---	---		---	---	---		---	---	---
246	---	---	---		350	25.2	208.7		339	25.2	198.0
247	---	---	---		339	25.2	202.5		345	25.2	200.2
250	---	---	---		333	25.2	---		---	---	---
276	---	---	---		242	25.2	160.2		---	---	---
DATE	12-17				12-18				12-30		
STATION	Bench				Bench				Bench		
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 4.2
(Con't)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP F01

				Bonded 3 Mil Copper-Constantan Thermocouple to Header Flange							
	7th Readout			8th Readout							
	ΔVBE at 500mw	TA	TJ at 500mw			ΔVBE at 500mw	TA	TJ at 500mw	TC at 500mw		
UNIT	mv	°C	°C			mv	°C	°C	°C		
MINIMUM											
MAXIMUM											
236	325	25.0	175.5			313	25.1	170.9	119.1		
239	---	---	---			---	---	---	---		
240	328	25.0	---			325	25.2	---	137.6		
242	331	25.0	200.0			324	25.2	193.5	127.6		
243	360	25.0	---			325	25.2	---	125.7		
244	332	25.0	195.0			322	25.3	189.3	134.9		
245	---	---	---			---	---	---	---		
246	350	25.0	205.3			335	25.3	199.3	146.0		
247	345	25.0	198.8			---	---	---	---		
250	333	25.4	---			330	25.3	---	156.3		
276	242	25.2	160.2			250	25.2	162.2	109.2		
DATE	1-3					1-5					
STATION	Bench					Bench					
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE PROGRAM
THERMOCOUPLE METHOD
(CALCULATED DATA)

TABLE 4.3

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP F01

Comparison of measured and calculated values of junction temperature.***

	Before T/C Bonded*	After T/C Bonded	R/O Data	1st Meas.	1st Calc.(2)	2nd Meas.	2nd Calc.	3rd Meas.	3rd Calc.	4th Meas.	4th Calc.
S/N	θJ-C at 500mw	θJ-C at 500mw	ΔθJ-C at 500mw	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
UNIT	°c/w	°c/w	%	°C	°C	°C	°C	°C	°C	°C	°C
MINIMUM											
MAXIMUM											
236	114	101	-11.4	175.8	187.9	179.7	204.0	168.2	193.0	169.3	188.3
Δ%M-C(1)					-6.9		-13.5		-14.0		-11.2
239	116	110	- 5.2	166.4	170.3	161.1	173.2	---	---	---	---
Δ%M-C					-2.4		-7.5		---		---
240	111	96	-13.5	---	---	---	---	---	---	189.3	193.8
Δ%M-C					---		---		---		-2.4
242	121	104	-14.0	---	---	196.7	205.4	195.1	203.1	195.6	200.8
Δ%M-C					---		-4.4		-4.1		-2.7
243	123	107	-13.0	---	---	194.6	209.1	196.1	208.4	196.1	211.9
Δ%M-C					---		-7.5		-6.3		-8.1
244	112	99	-11.6	---	---	199.0	213.1	193.9	206.6	196.6	205.9
Δ%M-C					---		-7.1		-6.6		-4.7
245	115	112	- 2.6	---	---	---	---	205.0	204.0	---	---
Δ%M-C					---		---		0.5		---
246	113	103	- 8.8	---	---	---	---	---	---	---	---
Δ%M-C					---		---		---		---
247	115	99	-13.9	---	---	---	---	---	---	---	---
Δ%M-C					---		---		---		---
250	111	99	-10.8	---	---	---	---	189.5	211.2	---	---
Δ%M-C					---		---		-11.5		---
276**	113	112	- 1.8	---	---	---	---	---	---	---	---
Δ%M-C					---		---		---		---

(1) % difference in measured value (M) and calculated value (C) calculated $\frac{M-C}{M}$ X 100.

(2) "K" factor of 1.84mv/°c used in all calculations.

DATE	STATION	INSP. STAMP
Before T/C Bonded: 12-6	H0-01	
After T/C Bonded: 12-8	H0-01	
1st: 12-9		
2nd: 12-11		
3rd: 12-13		
4th: 12-17		

REMARKS (*) Thermocouple bonded to emitter area by Omega Ht. Cement.
(**) Thermocouple stitch bonded to emitter wire bond at die.
(***) For 500mw in still ambient air.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1070

THERMAL RESISTANCE PROGRAM
THERMOCOUPLE METHOD
(CALCULATED DATA)

TABLE 4.3 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP F01

Comparison of measured and calculated values of junction and case temperature*.

R/O	5th		6th		7th		8th				MEAN VALUE
DATA	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	
S/N	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TC	TC (2)	(2) ΔTJ (M-C)
UNIT	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	%
MINIMUM											
MAXIMUM											
236	167.1	188.1	183.2	204.7	175.5	201.8	170.9	195.2	119.1	144.7	---
Δ%M-C		-12.6		-11.7		-15.0		-14.2		-21.5	-12.4
239	---	---	---	---	---	---	---	---	---	---	---
Δ%M-C		---		---		---		---		---	-5.0
240	189.9	192.1	(1)	195.4	---	203.5	---	202.0	137.6	154.0	---
Δ%M-C		-11.6		---		---		---		-11.9	-7.0
242	204.0	210.5	---	---	200.0	205.0	193.5	201.4	127.6	149.4	---
Δ%M-C		-3.2		---		-2.5		-4.1		-17.1	-3.5
243	191.7	205.2	191.2	210.6	---	220.7	---	202.0	125.7	148.5	---
Δ%M-C		-7.0		-10.2		---		---		-18.2	-7.8
244	198.5	208.2	191.7	209.0	195.0	205.5	189.3	200.3	134.9	150.8	---
Δ%M-C		-4.9		- 9.0		-5.4		-5.8		-11.8	-6.2
245	---	---	---	---	---	---	---	---	---	---	---
Δ%M-C		---		---		---		---		---	0.5
246	208.7	215.7	198.0	209.6	205.3	215.4	199.3	202.4	146.0	155.9	---
Δ%M-C		-2.3		-5.9		-4.9		-4.1		-6.8	-4.3
247	202.5	210.5	200.2	212.7	198.8	212.5	---	---	---	---	---
Δ%M-C		-4.0		-6.2		-6.9		---		---	-5.7
250	169.9 (1)	206.4	---	---	---	206.4	---	204.8	156.3	155.3	---
Δ%M-C		---		---		---		---		0.6	-11.5
276	160.2	156.8	---	---	160.2	156.8	162.2	161.2	109.2	105.2	---
Δ%M-C		2.1		---		2.1		0.6		-3.7	1.6
(*)	For 500mw in still ambient air.							MEAN VALUE:		-9.7%	-5.6%
DATE	12-18		12-30		1-3		1-5		1-5		
STATION											
INSP. STAMP						Page 4-31					

REMARKS (1) Thermocouple bond came loose from die.
(2) Calculated from θJ-C and calculated TJ rather than measured TJ. (3) Δ% between measured and Calculated values.

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE PROGRAM
THERMOCOUPLE METHOD
(CALCULATED DATA)

TABLE 4.3 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP F01

Computation of θJ-A and θC-A values for 500mw operation(2) in still ambient air.

	Mean Values for individual units					From Meas. Values	From Calc. Values	From Meas. Values	From Calc. Values	Δ% between Meas. & Calc. Values	
	Meas.	Calc.	Meas.	Calc.	Meas.						
S/N	TJ	TJ	TC	TC(3)	TA	θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°C	°C	°C	°C	°C	°c/w	°c/w	°c/w	°c/w	%	%
MINIMUM											
MAXIMUM											
236	173.5	195.5	119.1	145.0	25.1	297	341	188	240	-14.8	-27.7
239	163.6	171.8	---	116.8	24.9	278	294	---	184	-5.8	---
240	189.5	197.5	137.6	149.5	25.1	330	345	225	250	-4.5	-11.1
242	197.5	204.4	127.6	152.4	25.1	345	359	205	254	-4.1	-23.9
243	194.0	209.8	125.7	156.3	25.1	338	369	201	262	-9.2	-30.4
244	195.0	207.0	134.9	157.5	25.1	334	364	220	266	-9.0	-20.9
245	205.0	204.0	---	148.0	25.1	361	359	---	246	-0.6	---
246	203.0	212.0	146.0	160.5	25.1	355	374	242	272	-5.4	-12.4
247	200.6	212.0	---	162.5	25.1	351	374	---	276	-6.6	---
250	189.5	207.3	156.3	157.8	25.1	329	364	262	266	-10.6	-1.5
276(1)	161.0	158.4	109.2	102.4	25.2	272	266	168	154	2.2	8.3
Mean A	186.9	196.5	132.0	146.0	25.1	326	346	214	241	-6.1	-12.6
Mean B*	196.6	202.1	138.0	156.0	25.1	343	363	226	262	-5.8	-15.9

* - Mean B calculated without data from Units # 236, 239, and 276.

DATE

STATION (3) Calculated from mean TJ (calculated) and θJ-C

INSP. STAMP

REMARKS (1) Thermocouple stitch bonded to emitter wire bond at die. (2) With Cap "off" and Omega HT cement on die.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

Semiconductor Products Division

THERMAL RESISTANCE PROGRAM
DETECTO-TEMP PAINT EVALUATION SUMMARY

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)

TABLE 4.4

GROUP REY 098 SUBGROUP Paint Test

SUMMARY OF RESULTS OF TEMPERATURE TESTS OF "DETECTO-TEMP" PAINT

Detecto Temp Paint		1st Paint Color Change		2nd Paint Color Change		3rd Paint Color Change		4th Paint Color Change		Summary of Results	
Type Number 915-	Orig. Color	New Color	Temp.	New Color	Temp.	New Color	Temp.	New Color	Temp.	Meets Mfgrs. Specs.	Satis. for Project
UNIT	---	---	°C	---	°C	---	°C	---	°C	---	---
MINIMUM											
MAXIMUM											
0900	Pink & L. Blue	Blue	50°C	None		None		None		No	No
0901	Light Cream	L. Blue	60°C	"		"		"		Yes	Yes
0902	Pink & Blue	M. Blue	80°C-85°C	"		"		"		Yes	Yes
0903	Pink	Lilac	100°C	"		"		"		Yes	Yes
0904	Light Yellow	Violet	120°C	"		"		"		No	Yes
0905	Purple	None	(1)	"		"		"		No	No
0906	Blue	Gray-Green	140°C	M. Gray	155°C	D. Gray	170°C	"		No	Yes
0907	White	Yellow	180°C	None		None		None		Yes	Yes
0908	Green	L. Grn& L. Brn.	220°C	L. Brn& M. Brn.	225°C	M. Brn	230°C	"		Yes	Yes
0909	Gold-Brown	Orange	280°C	Rust	285°C	None		"		No	No
0910	White	Cream (2)	335°C	Yellow	340°C 345°C	"		"		Yes	No
0923	Pink	Lilac	85°C	Gray	230°C	"		"		No	No
0926	Bl-Grn.	L. Gray (2)	330°C	None		"		"		No	No
0927	Blue	L. Grn.	230°C	M. Gray	330°C	"		"		No	Yes
0931	Gold-Yellow	Lt. Brn-Brown	180°C 190°C	Gray	215°C	Violet-Gray	295°C	Brn-Gray	340°C	No	Yes
0934	Bl-Grn.	L. Blue	75°C	L. Gray	240°C	None		None		No	Yes

(1) No change from original color observed over the temperature range from 27°C to 205°C. Specification color change temperature was 140°C.

(2) Poor adherences to silicon wafer - majority of paint dots came off wafer at or from 5 to 10°C above specified color change temperature.

DATE		11-23	11-23	11-23	11-23	11-23	11-23	11-23	11-23		
STATION											
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 4.5

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP G01

"Detecto-Temp" temperature sensitive paint used in determining power levels required to change** paint colors at specific TJ levels.

After paint applied to Die & Header			Top Paint Dot on Die (Color changes at 75°C)			Bottom Paint Dot on Die (Color changes at 83°C)			Paint Dot on Header (Color changes at 60°C)		
S/N	θJ-C at 500mw	θJ-A* still Air	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA
UNIT	°c/w	°c/w	mw	---	°C	mw	---	°C	mw	---	°C
MINIMUM											
MAXIMUM											
251	117	379	132	---	26.5	136	150 at 95°C	26.5	124	---	26.5
252	113	375	133	---	26.8	138	---	26.8	130	---	26.8
253	103	365	140	---	26.8	200	---	26.8	136	---	26.8
254	---	---	---	---	---	---	---	---	---	---	---
255	108	370	146	---	26.5	170	240 at 95°C	26.5	136	---	26.5
256	117	379	---	(1)	26.3	---	(1)	26.3	136	---	26.3
257	102	364	---	(1)	26.0	---	(1)	26.0	120	---	26.0
258	113	375	130	---	26.0	136	220 at 95°C	26.0	124	---	26.0
259	112	375	120	---	26.0	124	180 at 95°C	26.0	110	---	26.0
260	119	381	110	---	26.0	116	180 at 95°C	26.0	100	---	26.0
DATE	12-27	1-5	1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18
STATION	H0-01	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP											

(1) Paint applied too thick to observe changes on die surface.

REMARKS (*) θC-A=262°c/w for unwelded TO-18 case in still air at 25°C.
(**) Color changes observed under microscope while power is increased slowly.

NAME
TITLE
DATE

THERMAL RESISTANCE DATA

TABLE 4.5 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP G02

"Detecto-Temp" temperature sensitive paint used in determining power levels required to change** paint colors at specific TJ levels.

After Paint applied to Die & Header			Top Paint Dot on Die (Color changes at 100°C)			Bottom Paint Dot on Die (Color changes at 120°C)			Paint Dot on Header (Color changes at 75°C)		
S/N	θJ-C at 500mw	θJ-A* still Air	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA
UNIT	°c/w	°c/w	mw	---	°C	mw	---	°C	mw	---	°C
MINIMUM											
MAXIMUM											
261	106	368	208	---	26.0	240	---	26.0	170	---	26.0
262	116	378	205	---	26.3	245	---	26.3	165	---	26.3
263	108	370	165	---	26.4	180	---	26.4	145	---	26.4
264	107	369	175	---	26.3	195	---	26.3	150	---	26.3
265	105	367	210	---	26.3	245	---	26.3	160	---	26.3
266	111	373	185	---	26.3	235	---	26.3	140	---	26.3
267	111	373	220	---	26.3	255	---	26.3	145	---	26.3
268	108	370	180	---	26.3	225	---	26.3	130	---	26.3
269	105	367	190	---	26.5	230	---	26.5	132	---	26.5
270	113	375	---	(1)	---	---	(1)	---	---	(1)	---
(1) This unit used to run paint check at elevated temperature.											
DATE	12-27	1-5	1-19	1-19	1-19	1-19	1-19	1-19	1-19	1-19	1-19
STATION	H0-01	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP						Page 4-35					

REMARKS (*) θC-A≅262°c/w for unwelded TO-18 case in still air at 25°C.
(**) Color changes observed under microscope while power is increased slowly.

NAME
TITLE
DATE

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP G03

TABLE 4.5 (Cont'd)

"Detecto-Temp" temperature sensitive paint used in determining power levels required to change** paint colors at specific TJ levels.

After Paint applied to Die &Header			Top Paint Dot on Die (Color changes at 140°C)			Bottom Paint Dot on Die (Color changes at 150°C)			Paint Dot on Header (Color changes at 100°C)		
S/N	θJ-C at 500mw	θJ-A* still Air	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA
UNIT	°c/w	°c/w	mw	---	°C	mw	---	°C	mw	---	°C
MINIMUM											
MAXIMUM											
271	160	422	240	---	26.5	310	350 at 170°C	26.5	260	---	26.5
272	103	365	---	(2)	26.5	---	(2)	26.5	310	260NR Die	26.5
273	103	365	---	(1)	---	---	(1)	---	---	(1)	---
274	110	372	330	---	26.3	360	420 at 170°C	26.3	260	250 NR Die	26.3
275	110	372	340	---	26.3	390	480 at 170°C	26.3	310	280 NR Die	26.3
DATE	12-27	1-5	1-19	1-19	1-19	1-19	1-19	1-19	1-19	1-19	1-19
STATION	110-01	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP											

(1) This unit used to run paint check at elevated temperatures.

(2) Paint applied too thick to observe changes on die surface.

REMARKS (*) θC-A≅262°c/w for unwelded TO-18 case in still air at 25°C.
(**) Color changes observed under microscope while power is increased slowly.

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 4.6

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL3-05)
GROUP REY 098 SUBGROUP K01

"Detecto-Temp" temperature sensitive paint used in determining power levels required to change** paint colors at specific TJ levels.

After Paint applied to Die & Header			Top Paint Dot on Die (color changes at 170°c)			Bottom PaintDot on Die (Color changes at 180°C)			Paint Dot on Header (Color changes at 120°C)		
S/N	θJ-C at 500mw	θJ-A* still Air	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA
UNIT	°c/w	°c/w	mw	---	°C	mw	---	°C	mw	---	°C
MINIMUM											
MAXIMUM											
34	109	371	340	---	26.5	420	---	26.5	340	320 NR Die	26.5
35	---	---	---	---	---	---	---	---	---	---	---
36	108	370	360	---	26.5	410	---	26.5	340	320 NR Die	26.5
37	108	370	340	---	26.5	380	---	26.5	300	270 NR Die	26.5
38	128	390	300	---	26.5	350	---	26.5	280	260 NR Die	26.5
39	111	373	320	---	26.5	340	---	26.5	280	250 NR Die	26.5
40	111	373	420	---	26.5	440	---	26.5	420	340 NR Die	26.5
41	104	366	460	---	26.5	500	---	26.5	450	340 NR Die	26.5
42	109	371	320	---	26.5	380	---	26.5	280	260 NR Die	26.5
43	108	370	380	---	26.5	440	---	26.5	360	300 NR Die	26.5
DATE	12-27	1-5	1-20	1-20	1-20	1-20	1-20	1-20	1-20	1-20	1-20
STATION	HO-01	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP											

REMARKS (*) θC-A≅262°c/w for unwelded TO-18 case in still air at 25°C.
(**) Color changes observed under microscope while power is increased slowly.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544(SL3-05)
GROUP REY 098 SUBGROUP L01

TABLE 4.6 (Cont'd)

"Detecto-Temp" temperature sensitive paint used in determining power levels required to change** paint colors at specific TJ levels.

After paint applied to Die & Header			Top Paint Dot on Die (color changes at 230°C)			Bottom Paint Dot on Die (Color changes at 240°C)			Paint Dot on Header (Color changes at 150°C)		
S/N	θJ-C at 500mw	θJ-A* still Air	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA	Power Level Appl'd	Notes	TA
UNIT	°c/w	°c/w	mw	---	°C	mw	---	°C	mw	---	°C
MINIMUM											
MAXIMUM											
45	117	379	580	560 at 225°C	26.5	650	180 at 75°C	26.5	480	440 NR Die	26.5
46	---	---	---	---	---	---	---	---	---	---	---
47	111	373	650	610 at 220°C	26.2	680	220 at 75°C	26.2	500	460 NR Die	26.2
48	109	371	530	510 at 225°C	26.2	580	200 at 75°C	26.2	430	400 NR Die	26.2
49	94	356	540	520 at 225°C	26.2	620	200 at 75°C	26.2	450	420 NR Die	26.2
50	---	---	---	---	---	---	---	---	---	---	---
51	110	372	540	530 at 225°C	26.2	560	180 at 75°C	26.2	400	360 NR Die	26.2
52	108	370	550	530 at 225°C	26.2	600	180 at 75°C	26.2	460	420 NR Die	26.2
53	107	369	580	540 at 220°C	26.2	620	180 at 75°C	26.2	480	460 NR Die	26.2
54	108	370	580	560 at 225°C	26.2	660	180 at 75°C	26.2	440	420NR Die	26.2
55	107	369	560	540 at 225°C	26.2	640	180 at 75°C	26.2	460	440 NR Die	26.2
DATE	12-27	1-5	1-21	1-21	1-21	1-21	1-21	1-21	1-21	1-21	1-21
STATION	HO-01	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP											

REMARKS (*) θC-A=262 °c/w for unwelded TO-18 case in still air at 25°C. (**) Color changes observed under microscope while power is increased slowly.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL3-05)
GROUP REY 098 SUBGROUP M01

TABLE 4.6 (Cont'd)

"Detecto-Temp" temperature sensitive paint used in determining power levels required to change** paint colors at specific TJ levels.

After paint applied to Die & Header			Top Paint Dot on Die (Color changes at 330°C)			Bottom Paint Dot on Die (Color changes at 340°C)			Paint Dot on Header (Color changes at 230°C)		
S/N	θJ-C at 500mw	θJ-A* still air	Power Level appl'd	Notes	TA	Power Level appl'd	Notes	TA	Power Level appl'd	Notes	TA
UNIT	°C/w	°c/w	mw	---	°C	mw	---	°C	mw	---	°C
MINIMUM											
MAXIMUM											
56	111	373	700 (1)	525 at 230°C	26.4	665	560 at 295°C	26.4	630	---	26.4
57	124	386	610 (2)	500 at 230°C	26.4	630	522 at 295°C	26.4	625	---	26.4
58	106	368	675 (1)	560 at 230°C	26.4	775	560 at 185°C	26.4	750	---	26.4
59	101	363	665 (1)	560 at 230°C	26.4	735	560 at 215°C	26.4	805	---	26.4
60	102	364	750 (1)	580 at 230°C	26.4	805	630 at 215°C	26.4	840	---	26.4
61	---	---	---	---	---	---	---	---	---	---	---
62	101	363	730 (1)	580 at 230°C	26.4	805	630 at 215°C	26.4	735	All HDR at 910	26.4
63	112	374	675 (1)	540 at 230°C	26.4	790	540 at 185°C	26.4	705	---	26.4
64	116	378	665 (1)	560 at 230°C	26.4	810	580 at 185°C	26.4	750	All HDR at 910	26.4
65	122	384	610 (2)	455 at 230°C	26.4	630	455 at 215°C	26.4	770	---	26.4
DATE	1-21	1-5	1-21	1-21	1-21	1-21	1-21	1-21	1-21	1-21	1-21
STATION	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP											

(1) Paint turned totally gray at about 1050 mw.

(2) Paint turned totally gray at about 980 mw.

Page 4-39

REMARKS (*) θC-A≅ 262°c/w for unweld ed TO-18 case in still air at 25°C. (**) Color changes observed under microscope while power is increased showly.

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 4.7

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL3-05)
GROUP REY 098 SUBGROUP A01

"Detecto-Temp" temperature sensitive paint used in determining TJ by application of design power levels and observing**paint color changes.

after paint applied & before cap welded		After welding cap to header				Top paint Dot on die 170°C		Bottom paint dot on die 180°C		Paint dot on header 120°C	
S/N	θJ-C at 500mw	θJ-C at 500mw	θJ-A* 100°C 500mw	Design junctn Temp.	Power Level Appld.	Did Color Change	Notes	Did Color Change	Notes	Did Color Change	Notes
UNIT	°c/w	°c/w	°c/w	°C	mw	---	---	---	---	---	---
MINIMUM											
MAXIMUM											
1	104	106	216	175	347	yes	---	no	---	no	---
2	109	111	221	175	339	yes	---	no	---	no	---
3	113	---	---	---	---	---	---	---	---	---	---
4	105	108	218	175	344	yes	---	no	---	no	---
5	101	---	---	---	---	---	---	---	---	---	---
6	186	192	302	175	248	yes	---	no	---	no	---
7	108	114	224	175	335	yes	---	no	---	no	---
8	114	120	230	175	326	yes	---	no	---	no	---
9	103	106	216	175	347	yes	---	no	---	no	---
10	109	111	221	175	339	yes	---	no	---	no	---
11	---	---	---	---	---	---	---	---	---	---	---
DATE	12-18	12-27	1-21		1-22	1-22	1-22	1-22	1-22	1-22	1-22
STATION	HO-01	HO-01	Bench		Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP						Page 4-40					

REMARKS (*) θC-A=110°c/w for TO-18 case in moving air at 100°C. (**) Under microscope after 2 min. appl. of power & removal of cap.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1078

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (S[illegible]-05)
GROUP REY 098 SUBGROUP B01

TABLE 4.7 (Cont'd)
"Detecto-Temp" Temperature Sensitive Paint Used in determining TJ by application of design power levels and observing** paint color changes.

After Paint applied &before cap welded		After welding cap to header				Top paint dot on die 230°C		Bottom paint dot on die 240°C		Paint dot on header 140°C	
S/N	θJ-C at 500mw	θJ-C at 500mw	θJ-A* 100°C 500mw	Design Junctn Temp.	Power Level Appl'd	Did Color Change	Notes	Did Color Change	Notes	Did Color Change	Notes
UNIT	°c/w	°c/w	°c/w	°C	mw	--	--	--	--	--	--
MINIMUM											
MAXIMUM											
12	112	116	226	235	597	yes	---	no	---	yes	---
13	101	105	215	235	628	yes	---	no	---	yes	---
14	110	116	226	235	597	yes	---	no	---	yes	---
15	106	111	221	235	611	yes	---	no	---	yes	---
16	122	126	236	235	572	no	---	no	---	yes	---
17	109	114	224	235	603	yes	---	no	---	yes	---
18	107	111	221	235	611	yes	---	yes	---	yes	---
19	103	108	218	235	620	yes	---	no	---	yes	---
20	---	---	---	---	---	---	---	---	---	---	---
21	---	---	---	---	---	---	---	---	---	---	---
22	110	114	224	235	603	yes	---	no	---	yes	---
DATE	12-18	12-27	1-21		1-22	1-22	1-22	1-22	1-22	1-22	1-22
STATION	H0-01	H0-01	Bench		Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP											

REMARKS (*) θC-A=110°C/W for TO-18 Case in moving air at 100°C. (**) Under microscope after 2 min. appl. of power & removal of cap.

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA
TABLE 4.7 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER Unwelded-544 (SL3-05)
GROUP REY 098 SUBGROUP C01

"Detecto-Temp" temperature sensitive paint used in determining TJ by application of design power levels and observing paint color changes.

	After paint applied &before cap welded	After welding cap to header				Top Paint Dot on Die 330°C		Bottom Paint Dot on Die 340°C		Paint Dot on Header 230°C	
S/N	θJ-C at 500mw	θJ-C at 500mw	θJ-A* 100°C 500mw	Design Junctn Temp.	Power Level Appl'd	Did Color Change	Notes	Did Color Change	Notes	Did Color Change	Notes
UNIT	°c/w	°c/w	°c/w	°c	mw						
MINIMUM											
MAXIMUM											
23	114	118	228	335	1030	yes	---	yes	Dirty white	yes	---
24	113	120	230	335	1025	yes	brown-yellow	yes	purple brown	yes	---
25	109	114	224	335	1050	yes	brown-yellow	yes	purple brown & lt. gray	yes	---
26	107	116	226	335	1040	yes	---	yes	gray-brown	yes	---
27	109	112	222	335	1060	yes	---	yes	brown-L gray	yes	---
28	103	106	216	335	1090	yes	---	yes	brown-L gray	yes	---
29	106	113	223	335	1055	yes	---	yes	brown-L gray	yes	---
30	104	108	218	335	1080	yes	---	yes	Brown-L gray	yes	---
31	110	114	224	335	1050	yes	---	yes	brown-L gray	yes	---
32	108	113	223	335	1055	yes	---	yes	brown-L gray	yes	---
DATE	12-18	12-27	1-21		1-22	1-22	1-22	1-22	1-22	1-22	1-22
STATION	H0-01	H0-01	Bench		Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP						Page 4-42					

REMARKS (*) θC-A=110°C/W for TO-18 Case in moving air at 100°C. (**) Under microscope after 2 min. appl. of power & removal of cap.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL IMPEDANCE PROGRAM
TEMPERATURE-INDICATING PAINT METHOD
(CALCULATED DATA)

TABLE 4.8

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP G01

Comparison of calculated power level and observed power level req'd to reach TJ and TH

	Ambient Temp.		Power req'd. to raise TJ to 75°C			Power req'd to raise TJ to 83°C			Power req'd to raise header to 60°C		
S/N	TA	θJ-A* still air	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error
UNIT	°C	°c/w	mw	mw	%	mw	mw	%	mw	mw	%
MINIMUM											
MAXIMUM											
251	26.5	379	128	132	-3.1	149	136	8.7	128	124	3.1
252	26.8	375	129	133	-3.1	150	138	8.0	127	130	-2.4
253	26.8	365	132	140	-6.1	154	200	-29.9	127	136	-7.1
254	---	---	---	---	---	---	---	---	---	---	---
255	26.5	370	131	146	-11.5	153	170	-11.1	128	136	-6.3
256	26.3	379	129	---	---	150	---	---	129	136	-5.4
257	26.0	364	135	---	---	157	---	---	130	120	7.7
258	26.0	275	131	130	0.8	152	136	10.5	130	124	4.6
259	26.0	275	131	120	8.4	152	124	18.4	130	110	15.4
260	26.0	381	129	110	14.7	150	116	22.7	130	100	23.1
MEAN ERROR:					6.8			15.6			8.3
DATE				1-18			1-18			1-18	
STATION											
INSP. STAMP						Page 4-43					

REMARKS *Based on θC-A of 262°c/w for unwelded TO-18 case in still air at 25°C.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL IMPEDANCE PROGRAM
TEMPERATURE-INDICATING PAINT METHOD
(CALCULATED DATA)

TABLE 4.8 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP G02

Comparison of calculated power level and observed power level req'd to reach TJ and TH

S/N	Ambient Temp. TA	θJ-A still air	Power req'd to raise TJ to 100°C: Calc. Power Level	Observ. Power Level	Error	Power req'd to raise TJ to 120°C: Calc. Power Level	Observ. Power Level	Error	Power req'd to raise header to 75°C: Calc. Power Level	Observ. Power Level	Error
UNIT	°C	°c/w	mw	mw	%	mw	mw	%	mw	mw	%
MINIMUM											
MAXIMUM											
261	26.0	368	201	208	-3.5	255	240	5.9	187	170	9.1
262	26.3	378	195	205	-5.1	248	245	1.2	186	165	11.3
263	26.4	370	199	165	17.1	253	180	28.9	185	145	21.6
264	26.4	369	199	175	12.1	254	195	23.2	186	150	19.4
265	26.3	367	201	210	-4.5	255	245	3.9	186	160	14.0
266	26.3	373	197	185	6.1	251	235	6.4	186	140	24.7
267	26.3	373	197	220	-11.7	251	255	-1.6	186	145	22.0
268	26.3	370	199	180	9.6	253	225	11.1	186	130	30.1
269	26.5	367	200	190	5.0	255	230	9.8	185	132	28.7
270	---	---	---	---			---		---	---	
MEAN ERROR:					8.3			10.2			20.1
DATE				1-19			1-19			1-19	
STATION											
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL IMPEDANCE PROGRAM
TEMPERATURE-INDICATING PAINT METHOD
(CALCULATED DATA)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP G03

TABLE 4.8 (Cont'd)

Comparison of calculated power level and observed power level req'd to reach TJ and TH

	Ambient Temp.		Power req'd to raise TJ to 140°C			Power req'd to raise TJ to 150°C			Power req'd to raise header to 100°C		
S/N	TA	ΘJ-A still air	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error
UNIT	°C	°c/w	mw	mw	%	mw	mw	%	mw	mw	%
MINIMUM											
MAXIMUM											
271	26.5	422	269	240	10.8	293	310	-5.8	280	260	7.1
272	26.5	365	311	---	---	338	---	---	280	310	-10.7
273	---	---	---	---	---	---	---	---	---	---	---
274	26.3	372	306	330	-7.8	333	360	-8.1	281	260	7.5
275	26.3	372	306	340	-11.1	333	390	-17.1	281	310	-10.3
MEAN ERROR:					9.9			10.3			8.9
DATE				1-19			1-19			1-19	
STATION											
INSP. STAMP											

REMARKS *Power levels 5 to 15% lower near die.

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL IMPEDANCE PROGRAM
TEMPERATURE-INDICATING PAINT METHOD
(CALCULATED DATA)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP K01

TABLE 4.8 (Cont'd)

Comparison of calculated power level and observed power level req's to reach TJ and TH

Ambient Temp.			Power req'd to raise TJ to 170°C			Power req'd to raise TJ to 180°C			Power req'd to raise header to 120°C		
S/N	TA	θJ-A still air	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error
UNIT	°C	°c/w	mw	mw	%	mw	mw	%	mw	mw	%
MINIMUM											
MAXIMUM											
34	26.5	371	387	340	12.1	414	420	-1.5	357	340	4.8
35	---	---	---	---	---	---	---	---	---	---	---
36	26.5	370	388	360	7.2	415	410	1.2	357	340	4.8
37	26.5	370	388	340	12.4	415	380	8.4	357	300	16.0
38	26.5	390	368	300	18.5	394	350	11.2	357	280	21.6
39	26.5	373	385	320	16.9	412	340	17.5	357	280	21.6
40	26.5	373	385	420	-9.1	412	440	-6.8	357	420	-17.7
41	26.5	366	392	460	-17.4	419	500	-19.3	357	450	-26.1
42	26.5	371	387	320	17.3	414	380	8.2	357	280	21.6
43	26.5	370	388	380	2.1	415	440	-6.0	357	360	-8.4
MEAN ERROR:					12.5			8.9			15.8
DATE				1-20			1-20			1-20	
STATION											
INSP. STAMP						Page 4-46					

REMARKS *Power levels 5 to 25% lower near die.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL IMPEDANCE PROGRAM
TEMPERATURE-INDICATING PAINT METHOD
(CALCULATED DATA)

TABLE 4.8 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP L01

Comparison of calculated power level and observed power level req'd to reach TJ and TH

Ambient Temp.			Power req'd to raise TJ to 230°C			Power req'd to raise TJ to 240°C			Power req'd to raise header to 150°C		
S/N	TA	θJ-A still air	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error
UNIT	°C	°c/w	mw	mw	%	mw	mw	%	mw	mw	%
MINIMUM											
MAXIMUM											
45	26.5	379	538	580	-7.8	564	650	2.5	472	480	-1.7
46	---	---	---	---	---	---	---	---	---	---	---
47	26.2	373	596	650	-19.0	574	680	-18.5	473	500	-5.7
48	26.2	371	550	530	3.6	577	580	-0.5	473	430	9.1
49	26.2	356	572	540	5.6	602	620	-3.0	473	450	4.9
50	---	---	---	---	---	---	---	---	---	---	---
51	26.2	372	548	540	1.5	575	560	2.6	473	400	15.4
52	26.2	370	552	550	0.4	578	600	-3.8	473	460	2.8
53	26.2	369	553	580	-4.9	580	620	-6.9	473	480	-1.5
54	26.2	370	552	580	-5.1	578	660	-14.2	473	440	7.0
55	26.2	369	553	560	-1.3	580	640	-10.3	473	460	2.8
MEAN ERROR:					5.5			6.9			5.6
DATE				1-21			1-21			1-21	
STATION											
INSP. STAMP						Page 4-47					

REMARKS *Power levels 5 to 10% lower near die.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL IMPEDANCE PROGRAM
TEMPERATURE-INDICATING PAINT METHOD
(CALCULATED DATA)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP M01

TABLE 4.8 (Cont'd)

Comparison of calculated power level and observed power level req'd to reach TJ and TH

	Ambient Temp.		Power req'd to raise TJ to 330°C			Power req'd to raise TJ to 340°C			Power req'd to raise header to 230°C		
S/N	TA	θJ-A still air	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error	Calc. Power Level	Observ. Power Level	Error
UNIT	°C	°c/w	mw	mw	%	mw	mw	%	mw	mw	%
MINIMUM											
MAXIMUM											
56	26.4	373	814	700	14.0	840	665	20.8	777	630	18.9
57	26.4	386	786	610	22.4	812	630	22.4	777	625	19.6
58	26.4	368	824	675	18.1	852	775	9.0	777	750	3.5
59	26.4	363	836	665	20.5	864	735	14.9	777	805	-3.6
60	26.4	364	834	750	10.1	862	805	6.6	777	840	-8.1
61	---	---	---	---	---	---	---	---	---	---	---
62	26.4	363	836	730	12.7	864	805	6.8	777	735	5.4
63	26.4	374	812	675	16.9	838	790	5.7	777	705	9.3
64	26.4	378	804	665	17.3	830	510	2.4	777	750	3.5
65	26.4	384	791	610	22.9	817	630	22.9	777	770	0.9
MEAN ERROR:					17.2			12.4			8.1
DATE				1-21			1-21			1-21	
STATION											
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 4.9

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531
GROUP REY 098 SUBGROUP Water Bath

Verification of Bench θJ-C measurement accuracy by water bath method

"K" Factor = -1.84mv/°c
IC = 40mA
VCE = 12.5V

Test device immersed in circulating deionized water for all measurements.

S/N	ΔVBE at 500mw		θJ-C at 500mw		TC Cold Water		VBE Cold		TC (1) Hot Water		VBE Hot
UNIT	mv		°c/w		°c		Volts		°C		Volts
MINIMUM											
MAXIMUM											
5	113		122.8		23.2		.683		85.6		.570
DATE	11-24		11-24		11-24		11-24		11-24		11-24
STATION	Bench		Bench		Bench		Bench		Bench		Bench
INSP. STAMP						Page 4-49					

(1) Hot water temperature adjusted to level required for change in VBE from cold water value to be 113 millivolts. This corresponds with the ΔVBE value observed on the bench tester when device was dissipating 500 milliwatts.

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE PROGRAM
WATER-BATH METHOD
(CALCULATED DATA)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 531 (SL3-05)
GROUP REY 098 SUBGROUP WATER-BATH TEST

TABLE 4.10

Calculation of θJ-C from bench test and by water-bath method.

θJ-C measured on bench tester.			θJ-C calculated by determining change in water-bath temperature req'd to produce same ΔVBE as bench tester.								
S/N		θJ-C at 500 mw		ΔVBE		ΔTC		θJ-C at 500 mw		Error	
UNIT		°c/w		mv		°C		°c/w		%	
MINIMUM											
MAXIMUM											
5		122.8		113		62.4		124.8		1.6	
DATE	12-6	1-24		1-24		1-24		1-24			
STATION	Bench	Bench		Water		Water		Water			
INSP. STAMP				Bath		Bath		Bath			

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

REPEATABILITY TEST
Transistor Type 2N2222
Lot 544 (SL3-05)
REY 098 E01
VCE = 11.9V, IC = 42mA

SERIAL NO.	READOUT (°C/W)										C.V.
	1	2	3	4	5	6	7	8	9	10	%
126	111	113	115	114	114	117	113	112	113	112	1.059
127	112	109	115	111	112	109	109	108	107	112	2.186
128	106	106	105	105	103	107	104	105	103	105	1.227
129	117	116	117	117	116	117	116	116	115	118	.729
130	112	111	112	116	111	112	111	112	113	110	1.458
131	114	114	113	114	114	111	112	110	110	114	1.521
132	135	134	135	133	133	133	133	131	135	130	1.266
133	115	114	117	113	118	116	114	112	113	114	1.656
134	119	117	120	120	116	119	117	119	117	118	1.183
135	112	113	114	111	114	113	114	113	112	112	.916
136	121	122	122	123	122	123	123	122	123	123	.571
137	112	110	112	113	113	112	109	110	110	112	1.274
138	120	117	117	119	115	116	117	117	117	116	1.238
139	121	114	113	115	115	112	113	114	113	114	2.188
140	111	107	109	109	108	107	107	107	109	108	1.217
141	118	115	113	113	114	112	113	113	113	112	1.564
142	124	127	125	127	126	125	125	124	123	126	1.052
143	142	142	143	143	140	142	143	142	142	144	.744
144	114	115	117	116	115	115	116	117	115	118	1.062
145	121	119	121	122	121	118	119	120	118	121	1.179
146	112	113	112	112	111	113	111	112	112	113	.658
147	113	112	109	111	111	110	113	111	110	109	1.307
148	122	122	122	119	121	120	121	120	122	119	1.018
149	118	117	115	115	114	115	113	112	114	119	1.911
150	115	116	117	117	116	117	116	115	116	114	.858

Table 4.11

REPEATABILITY TEST
Transistor Type 2N2222
Lot 544 (SL3-05)
REY 098 E01
VCE = 11.9V, IC = 42mA

SERIAL NO.	READOUT (°C/W)										C.V.
	1	2	3	4	5	6	7	8	9	10	%
151	117	117	116	115	118	114	116	116	115	115	1.033
152	111	111	112	113	114	113	111	112	110	111	1.100
153	112	114	110	111	109	109	107	110	110	110	1.700
154	111	108	112	109	111	110	108	107	109	108	1.497
155	109	111	109	111	109	110	109	108	108	109	.969
156	114	114	114	114	113	113	112	111	110	110	1.467
157	108	109	108	108	107	109	106	108	108	107	.852
158	113	111	112	110	111	112	110	111	109	108	1.350
159	120	121	120	121	124	124	122	120	120	120	1.336
160	118	116	120	118	116	117	115	116	116	116	1.263
161	113	116	113	114	112	112	113	111	110	112	1.462
162	119	115	115	113	116	114	115	114	116	114	1.445
163	128	129	126	130	127	126	128	127	126	125	1.218
164	100	101	102	103	100	104	101	102	101	101	1.251
165	120	117	118	121	119	119	119	118	118	117	1.067
166	116	117	112	115	115	114	113	113	112	112	1.573
167	111	113	113	113	112	110	109	111	112	110	1.284
168	122	118	120	118	120	120	116	117	117	121	1.656
169	123	119	118	119	119	118	118	118	117	117	1.444
170	122	123	121	123	122	121	123	123	123	123	.689
171	110	110	111	112	108	108	112	111	111	110	1.286
172	122	118	118	119	117	117	121	120	119	119	1.372
173	111	112	110	113	114	114	113	113	112	113	1.128
174	112	111	113	112	111	109	109	109	110	110	1.293
175	116	115	113	117	116	114	112	117	114	117	1.557

Table 4.11 (Cont.)

REPEATABILITY TEST
Transistor Type 2N2222
Lot 544 (SL3-05)
REY 098 E01
VCE = 11.9V, IC = 42mA

SERIAL NO.	READOUT (°C/W)										C.V.
	1	2	3	4	5	6	7	8	9	10	%
176	120	120	117	119	118	120	117	118	119	120	1.035
177	117	118	119	118	119	121	118	117	119	119	.995
178	125	123	125	123	126	125	122	124	124	125	.990
179	125	126	122	122	123	121	121	123	122	121	1.397
180	112	109	110	110	110	111	111	110	110	109	.834
181	112	114	114	113	111	112	112	112	111	112	.943
182	118	122	118	120	117	116	117	121	118	119	1.600
183	111	107	109	111	108	109	107	108	109	109	1.285
184	117	115	115	117	115	117	114	115	116	117	.980
185	110	108	111	109	106	105	108	108	108	106	1.717
186	108	111	111	109	108	110	109	108	107	107	1.356
187	118	120	120	118	115	117	116	118	120	119	1.464
188	108	112	108	109	108	107	109	108	108	110	1.305
189	118	118	119	116	116	118	117	117	116	118	1.000
190	109	112	109	109	109	113	110	109	109	112	1.449
191	117	116	114	116	116	116	115	115	114	114	.919
192	112	113	114	112	112	113	113	111	111	112	.845
193	115	113	111	113	114	112	113	111	112	112	1.123
194	119	120	119	118	116	118	120	118	117	119	1.068
195	119	123	124	122	121	119	121	120	123	121	1.404
196	110	110	113	110	110	110	110	109	108	109	1.171
197	114	113	111	115	113	112	111	110	112	114	1.405
198	111	113	114	113	112	114	112	112	112	113	.858
199	116	117	114	115	115	115	117	113	115	117	1.170
200	107	107	108	107	108	106	105	106	106	106	.906

Table 4.11 (Cont.)

REPEATABILITY TEST
Transistor Type 2N2222
Lot 544 (SL3-05)
REY 098 E01
VCE = 11.9V, IC = 42mA

SERIAL NO.	READOUT (°C/W)										C.V.
	1	2	3	4	5	6	7	8	9	10	%
201	113	112	111	111	113	113	110	112	113	115	1.263
202	119	120	118	121	120	117	118	117	117	117	1.272
203	106	110	108	105	107	107	105	107	108	108	1.423
204	120	120	118	120	119	119	119	119	117	118	.836
205	115	116	117	118	116	115	114	114	113	113	1.445
206	122	121	118	118	121	118	116	120	123	123	2.003
207	112	112	112	114	116	111	116	114	114	113	1.510
208	110	112	111	109	109	114	114	112	112	109	1.738
209	111	117	113	112	110	112	113	110	110	110	1.969
210	110	112	110	110	109	107	108	108	108	110	1.351
211	125	126	125	126	128	125	127	124	125	125	.935
212	114	112	112	111	112	113	112	110	115	110	1.423
213	120	123	123	119	121	123	122	123	123	123	1.222
214	116	113	116	115	112	114	112	113	113	116	1.432
215	111	110	111	112	112	112	110	110	110	110	.829
216	97.1	100	100	98.4	97.8	98.2	96.5	98.0	96.6	96.5	1.337
217	127	122	125	123	125	121	120	123	124	123	1.669
218	109	106	107	105	106	108	106	105	105	105	1.317
219	112	116	112	112	113	114	113	113	115	112	1.235
220	109	111	112	114	113	112	113	112	113	110	1.362
221	126	126	126	126	123	126	124	123	123	125	1.121
222	117	114	116	115	113	114	115	113	114	114	1.109
223	116	117	116	118	116	117	118	120	118	117	1.067
224	112	114	111	116	112	113	112	112	112	112	1.270
225	105	106	110	105	107	106	107	107	107	109	1.492

Table 4.11 (Cont.)

5.0 PHASE III TESTS - MEASUREMENT OF θJ-A

5.1 Test Design and Modifications of Original Test Program

Due to problems or circumstances not contemplated at the time the Motorola proposal was submitted, several modifications of the original test program were necessary. In no case was the scope, intent, or effort on the program reduced.

5.1.1 Measurement of θC-A

Due to instrumentation problems and handling difficulties associated with 3 mil copper-constantan thermocouples bonded to the cases of the 2N2222 devices, the original sample size was reduced from 25 to 6. Multiple readouts were made to compensate for the smaller sample. The power levels used were modified from the proposed 250-500-833mW to 500-662-778mW to permit the case temperature verification tests (Section 5.5) to be performed with available types of Detecto-Temp temperature-indicating paint. The thermocouples were bonded to the index tab of the header flange for solid bonding properties rather than to points determined by prior experimentation. The test program was expanded to include θC-A measurements in still ambient air, in moving ambient air, and in 125°C moving air, as well as the proposed 100°C moving air test.

5.1.2 Measurement of Maximum Junction Temperature

Since the devices for this test were identical to those used for θC-A measurements, the problems and program changes described in Section 5.1.1 above also apply. In addition, the forward voltage drop of the base-emitter diode (VBE) was measured at a current of 2.0mA rather than the originally proposed 100μA to permit working in a more linear (and thus repeatable) portion of the diode forward characteristic.

5.2 Method used for Determining θJ-A

Since the path of flow for the heat dissipated in a transistor junction is through the series path consisting of the θJ-C and θC-A of the device, the total thermal resistance between junction and ambient (θJ-A) must be the sum of θJ-C and θC-A. Expressed mathematically,

$$\theta J\text{-}A = \theta J\text{-}C + \theta C\text{-}A \qquad (1)$$

A method for accurately measuring θJ-C for individual transistors was developed during Phase I tests (see Section 3.1). Therefore, if an accurate method of measuring θC-A were to be developed, θJ-A could be calculated from equation (1).

θC-A is defined by equation (2) below and is essentially a function of the package and ambient air conditions. It is the same for all transistors mounted in the same package under the same ambient air conditions.

Since the proposed JPL Accelerated Life Test Program testing is to be performed in forced air (horizontal flow) ovens at +100°C, the value of $\theta C\text{-}A$ for the TO-18 package (used for 2N2222) was determined under these particular conditions. It was also determined for still ambient air, moving ambient air, and 125°C moving air.

$$\theta C\text{-}A = \frac{TC - TA}{P} \qquad \text{where } TC = \text{Case Temperature},\quad TA = \text{Ambient Temperature},\quad P = \text{Power Dissipation} \tag{2}$$

The actual value of $\theta C\text{-}A$ was found by accurately measuring TC, TA, and P, and calculating $\theta C\text{-}A$ using equation (2). The measurement technique used for determining $\theta C\text{-}A$ is described in the next section.

5.3 Measurement of $\theta C\text{-}A$

To perform the $\theta C\text{-}A$ measurements, an oven with socket configurations and air flow characteristics similar to the type that would be used on the proposed JPL Accelerated Life Test Program was fabricated. Six Motorola 2N2222 devices (from production lot 544), selected on the basis of their original $\theta J\text{-}C$ values, had 3 mil copper-constantan thermocouples bonded (Eastman 910 cement) to the transistor case (TO-18) at the point where the index tab extended from the welding flange. The devices were retested for $\theta J\text{-}C$ on tester HO-01. No significant change in $\theta C\text{-}A$ resulted from bonding the thermocouples.

Initial testing was performed on three units in still ambient air at the 500mW power level. The case temperature was measured with the 3 mil thermocouples on a Honeywell Model 2733 potentiometer. Room ambient temperature was read on an expanded scale (.1°C/division) laboratory thermometer. The change in VBE was measured on the bench tester using the Tektronix CRO.

The three devices were loaded into the test sockets in the oven and the thermocouple leads brought out for connection to the potentiometer. The oven blower was turned on but the heating elements were left off and measurements were made of TC and ΔVBE with 500mW applied in moving ambient air. The oven was stabilized at +100°C (monitored by another copper-constantan thermocouple located inside the oven). Power (500mW) was applied to the devices through the bench tester circuit so that the power level could be accurately measured and the value of ΔVBE determined. The thermocouple attached to the case of the transistor under test was monitored until the TC reading had stabilized. This value of case temperature and power level, together with the 100°C ambient temperature, was used to calculate θC-A for the 100°C moving air condition.

Following these initial experiments with three devices, all six units were measured in still ambient air and moving ambient air at the 500mW power level. The six test devices then had several dots of Detecto-Temp temperature-indicating paint applied to selected points on the outside of the case for the case temperature measurement verification test (see Section 5.5). The devices were then tested in 100°C moving air at the 500mW, 662mW, and 778mW power levels. Following operation at each power level, starting with the 500mW level, the oven door was opened briefly for visual examination of the temperature-indicating paint dots.

The initial data taken on the θC-A measurement experiments is presented on Pages 1 through 3 of Table 5.1. The calculated case temperature values and comparisons with measured values are shown on the first page of Tables 5.2 through 5.6. Since the measured TC values generally ran lower than the calculated values, it was decided that the Eastman 910 cement used to bond the thermocouples to the cases had provided an insulating layer under the thermocouple on some devices. This same problem had been experienced in the "Thermocouple Method" tests described in Section 4.2. Accordingly, the bonded thermocouples were removed and then soldered to the index tab. The still ambient air test was repeated on four devices and the moving ambient air tests were repeated on all devices. It was intended that the 100°C moving air test be repeated. However, due to switching from a thermocouple with an ice bath reference to one with a room reference for monitoring the oven temperature, the oven temperature was mistakenly set to 100°C rather than 75°C above room ambient. This raised the oven temperature to approximately 125°C, so the data taken was for 125°C moving air rather than the 100°C. An additional test of all six units was made, however, to repeat the 100°C moving air condition. The data taken on the tests repeated with soldered thermocouples is shown on Pages 4 through 6 of Table 5.1. The calculated case temperatures and comparisons with measured values are shown on Page 2 of Tables 5.2 through 5.4 and on Page 1 of Tables 5.5 through 5.9.

It was observed that the data obtained with the soldered thermocouples still had considerable variation between measured case temperature values for all devices at a given power level and ambient air condition. This was also true between measured and calculated values for individual devices. A series of tests were then performed to determine if soldering the thermocouples to the cases had damaged the devices or the thermocouples, or if the operation in 125° moving air at 778mW had caused damage. Water bath "K" factor measurements were performed (Page 7 of Table 5.1) and the calculated values for "K" (Page 1 of Table 5.10) indicated that the temperature coefficient was approximately -1.6mW/°C rather than the -1.84mV/°C used in calculating case temperature. However, when the test was repeated (Page 8 of Table 5.1) with the water bath temperatures measured using a different copper-constantan thermocouple, the temperature coefficient appeared to be about normal (Page 1 of Table 5.10). A comparison test was then made between the temperature readings of the soldered 3 mil thermocouples on four of the test devices and a Standards Lab copper-constantan thermocouple with an ice bath reference junction. Measurements were made in still ambient air, room ambient water, and hot water. At the same time, an unsoldered 3 mil copper-constantan thermocouple of the same type as those soldered to the cases and a standard glass laboratory thermometer were tested for apparent temperature accuracy. The data taken is shown on Page 7 of Table 5.1. The percentage deviations of the thermocouples and thermometer from the Standards Lab "Reference" thermocouple are shown on Page 1 of Table 5.10. The apparent deviations between thermocouples were very significant (up to 14%) at room temperatures but were insignificant (less than 1%) at the higher temperatures. Another water bath "K" factor test was performed (Page 8, Table 5.1) with test unit #373 using both the 3 mil thermocouple soldered to the case and the "Reference" thermocouple from the Standards Lab. The calculated data for the soldered thermocouple yielded a temperature coefficient 8.2% lower than the "Reference" thermocouple (Page 2 of Table 5.10).

At this point, all 3 mil thermocouples were unsoldered from the test units, cleaned thoroughly, examined under a 10-40 power microscope, and then resoldered to the test devices (except for unit #375 - the 3 mil thermocouple broke during the unsoldering operation). The thermocouples and the attached test units were individually calibrated by the Motorola Quality Control Temperature Standards Laboratory. A copy of one of the calibration curves is shown in Figure 7. The five test devices with newly soldered and calibrated thermocouples were again measured for "K" factor by the water bath method and compared with the "Reference" thermocouple (Page 9, Table 5.1). The results (Page 2, Table 5.10) were essentially the same as before with the soldered thermocouples yielding "K" factors about 6.5% lower than those computed from the "Reference" thermocouple. The "Reference" thermocouple was then sent to the Temperature Standards Lab for an accuracy check and found to be within acceptable limits (better than $\pm.05$°C at 25°C). The reason for the lower "K" factor values when using the soldered thermocouples had not been determined at the time the program was completed.

Since the series of measurements with thermocouples did not resolve the differences seen in the calculated "K" factor values (to possibly explain variations seen in calculated TC), the

MOTOROLA INC.
Semiconductor
Products Division

FIGURE 7

TEMPERATURE STANDARDS LAB

THERMOCOUPLE CALIBRATION CURVE

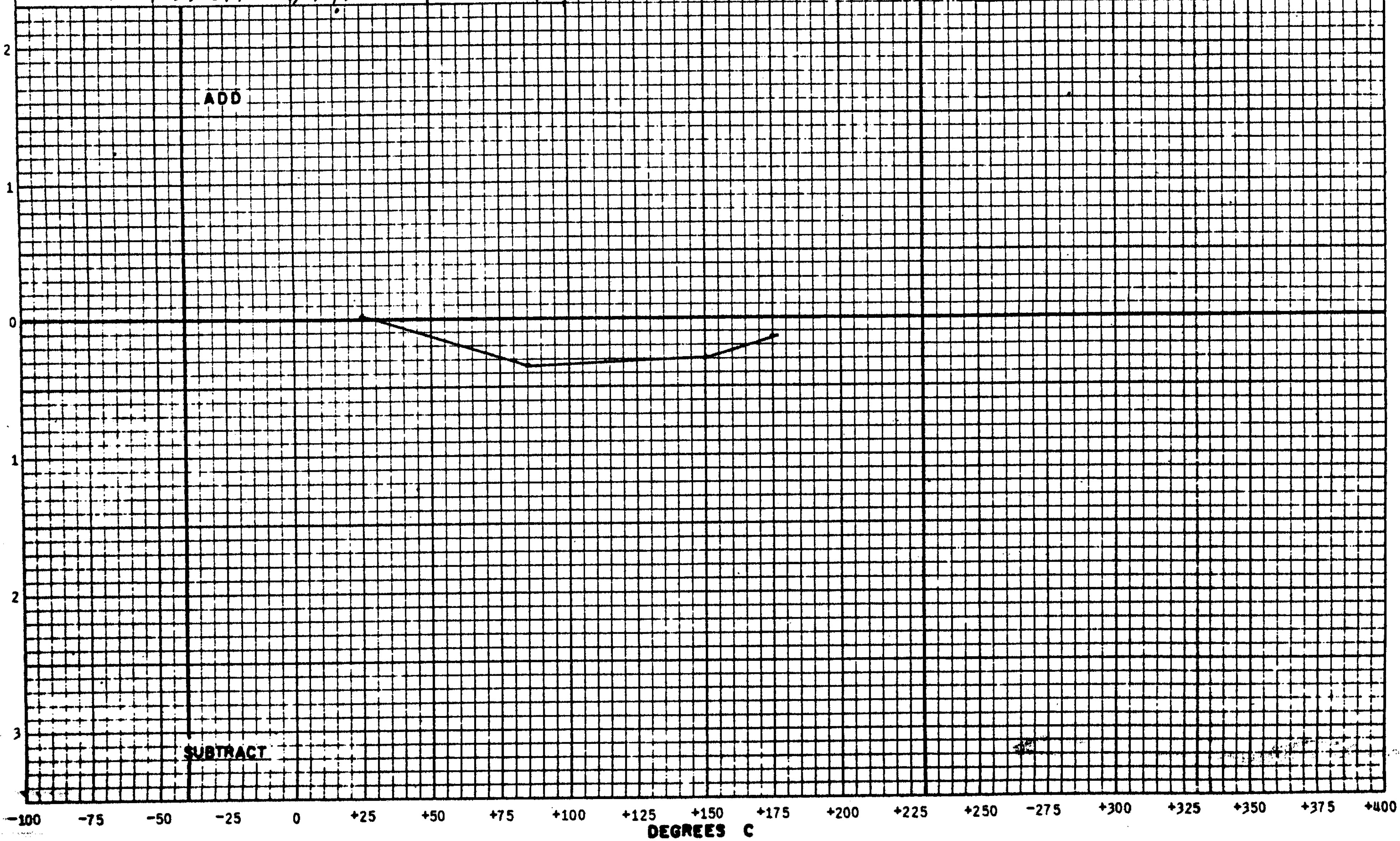
STD. TEMP.	MEASURED M.V.	MEASURED TEMP.	CORRECTION	#
24.73°C	.9786	24.72°C	+.01	
85.87°C	3.6394	86.20°C	-.33	
150.91°C	6.7585	151.21°C	-.30	
174.49	7.9611	174.67°C	-.12	

LOCATION:

SERIAL NO. #376

CALIBRATION: 1-19-66

CALIB. DUE:



MOTOROLA FORM NO. SPD-1150-R1

the devices were remeasured on θJ-C using the bench tester and water bath technique developed during Phase I tests (Page 9, Table 5.1). The new value of θJ-C was compared with the value obtained on tester HO-01 prior to the start of Phase II and III tests (Page 1, Table 5.10). The correlation with original values of θJ-C was very good with a mean difference of 2.0% and maximum deviation of only 4.8%. This indicated that the "K" factor value of -1.84mW/°C was still valid for the test units and that they had not been damaged by soldering on the thermocouples or by operating in 125°C moving air at 778mW. The five remaining test units were measured again (Page 10, Table 5.1) in still ambient air with values of ΔVBE and TC determined at the 500mW power level. The calculated values of TC and comparisons with measured values are shown on Page 2 of Table 5.2. The 100°C moving air test was also performed one additional time (Page 11, Table 5.1) at the 500mW, 662mW, and 778mW power levels to verify results obtained previously. The calculated values of TC and comparisons with measured values are shown on Page 2 of Table 5.4 (500mW level), Page 1 of Table 5.5 (662mW level), and Page 1 of Table 5.6 (778mW level).

The results of measurements made in still ambient air were very satisfactory. The difference between measured and calculated TC on individual readouts varied between 0.6% and 16.4%, while the mean difference for individual devices ranged from 5.0% to 7.9% with an overall mean difference of 6.5%. The mean difference between calculated and measured values of θC-A for individual units varied from 2.3% to 7.7% with an overall mean difference of 5.3%. The mean value of measured θC-A was 205.3°C/W compared to 204.7°C/W for the calculated value. An error of 10% in θC-A would correspond to an error in TJ of 5.6% (≈10°C) for a device with a θJ-C of 110°C/W operating at 500mW in still ambient air (TJ nominally 183°C).

The results of measurements made in moving ambient air were also very good. The difference between measured and calculated TC on individual readouts varied between 0.2% and 23.3% while the mean difference for individual devices ranged from 3.8% to 15.6% with an overall mean difference of 8.8%. The mean difference between calculated and measured values of θC-A for individual units varied from 2.3% to 21.8% with an overall mean difference of 8.6%. The mean value of measured θC-A was 114.0°C/W compared to 122.0°C/W for the calculated value (7% max. difference). An error of 10% in θC-A would correspond to an error in TJ of 4.3% (≈6°C) for a device with a θJ-C of 110°C/W operating at 500mW in moving ambient air (TJ nominally 139°C).

The results of measurements made in 100°C moving air were good at all three power levels. At 500mW, the difference between measured and calculated TC on individual readouts varied between 0.1% and 16.7%, while the mean difference for individual devices ranged from 2.6% to 8.9% with an overall mean difference of 5.3%. The mean difference between calculated and measured values of θC-A for individual units varied from 6.1% to 19.7% with an overall mean difference of 12.9%. The mean value of measured θC-A was 94.1°C/W compared to 106.2°C/W for the calculated value (12.9% max. difference). An error of 10% in θC-A would correspond to an error in TJ of 2.4% (≈5°C) for a device with a θJ-C of 110°C/W operating at 500mW in 100°C moving air

(TJ nominally 205°C). At 662mW, the difference between measured and calculated TC on individual readouts varied between 0.4% and 15.4% while the mean difference for individual devices ranged from 6.4% to 12.7% with an overall mean difference of 9.4%. The mean difference between calculated and measured values of θC-A for individual units varied from 2.3% to 14.3% with an overall mean difference of 8.9%. The mean value of measured θC-A was 95.9°C/W compared to 104.1°C/W for the calculated value (8.6% max. difference). An error of 10% in θC-A would correspond to an error in TJ of 2.8% (≈7°C) for a device with a θJ-C of 110°C/W operating at 662mW in 100°C moving air (TJ nominally 239°C). At 778mW, the difference between measured and calculated TC on individual readouts varied between 0.2% and 20.5% while the mean difference for individual devices ranged from 0.2% to 15.8% with an overall mean difference of 8.2%. The mean difference between calculated and measured values of θC-A for individual units varied from 5.3% to 18.3% with an overall mean difference of 10.3%. The mean value of measured θC-A was 104.5°C/W compared to 113.9°C/W for the calculated value (9.0% max. difference). An error of 10% in θC-A would correspond to an error in TJ of 3.1% (≈9°C) for a device with a θJ-C of 110°C/W operating at 778mW in 100°C moving air (TJ nominally 271°C).

The results of measurements made in 125°C moving air were also very good at all three power levels. At 500mW, the difference between measured and calculated TC on individual devices varied from 0.7% to 2.4% with an overall mean difference of 1.7%. The mean difference between calculated and measured values of θC-A for individual units varied from 2.3% to 7.3% with an overall mean difference of 5.2%. The mean value of measured θC-A was 118.2°C/W compared to 116.5°C/W for the calculated value (1.5% max. difference). An error of 10% in θC-A would correspond to an error in TJ of 2.5% (≈6°C) for a device with a θJ-C of 110°C/W operating at 500mW in 125°C moving air (TJ nominally 239°C). At 662mW, the difference between measured and calculated TC on individual devices varied from 0.5% to 5.1% with an overall mean difference of 2.7%. The mean difference between calculated and measured values of θC-A for individual units varied from 5.2% to 13.7% with an overall mean difference of 9.9%. The mean value of measured θC-A was 116.6°C/W compared to 109.2°C/W for the calculated value (6.8% max. difference). An error of 10% in θC-A would correspond to an error in TJ of 2.8% (≈8°C) for a device with a θJ-C of 110°C/W operating at 662mW in 125°C moving air (TJ nominally 273°C). At 778mW, the difference between measured and calculated TC on individual devices varied from 0.4% to 4.5% with an overall mean difference of 2.3%. The mean difference between calculated and measured values of θC-A for individual units varied from 1.0% to 11.0% with an overall mean difference of 5.5%. The mean value of measured θC-A was 120.9°C/W compared to 116.4°C/W for the calculated value (3.9% max. difference). An error of 10% in θC-A would correspond to an error in TJ of 3.1% (≈9°C) for a device with a θJ-C of 110°C/W operating at 778mW in 125°C moving air (TJ nominally 303°C).

The overall mean value of calculated θC-A for all three power levels and for both 100°C and 125°C moving air was found to be 111.3°C/W. A nominal value of 110°C/W for θC-A was selected for use in calculating power levels for the 100°C moving air experiments with temperature-indicating paint (see Section 4.4, Experiments A01, B01, and C01) and for recalculating the power levels for use on the proposed JPL Accelerated Life Test Program (see Section 6.2). The mean value computed from the calculated values of $\theta C\text{-}A$ was selected in preference to that computed from the measured values because the accuracy of the calculated values was more firmly established from the Phase II tests (Section 4.0). Also, thermocouple bonding problems had been experienced and the validity of measuring the true case temperature on the index tab of the welding flange was somewhat questionable, which added support to the decision to use the calculated values.

5.4 Measurement of Maximum Junction Temperature

This series of experiments was so closely associated with the measurement of $\theta C\text{-}A$ (Section 5.3) that the tests were performed simultaneously. The test procedure described in detail in Section 5.3 will suffice for the maximum TJ test program with the added notation that all the references made to the measurement of ΔVBE pertain specifically to the maximum TJ experiments.

By applying power to the devices in this test through the bench tester, the circuitry permitted the power to each individual transistor to be switched off and a 2.0mA forward bias (sense) current to be automatically applied through the emitter-base diode. The value of the forward voltage drop across the emitter-base diode (VBE) within approximately 1μsec from the time power was removed was observed on a calibrated Tektronix CRO. By using the measured ambient temperature (TA) and the "K" factor of -1.84mV/°C (which had been determined specifically for the Motorola

2N2222 during Phase I tests), the change (ΔVBE) in the value of VBE between a "no power" and "power" condition was converted directly to maximum junction temperature ($TJ = TA + \frac{\Delta VBE}{K}$). The observed values for ΔVBE and TA for these experiments are shown in Table 5.1. The calculated values of maximum junction temperature (TJ) are shown in Tables 5.2 through 5.9.

In summary, the values of maximum junction temperatures ranged from 171.6°C to 197.2°C for 500mW operation in still ambient air, from 141.0°C to 144.2°C for 500mW operation in moving ambient air, from 201.2°C to 213.2°C for 500mW operation in 100°C moving air, from 239.5°C to 243.9°C for 662mW operation in moving air, from 272.5°C to 282.5°C for 778mW operation in 100°C moving air, from 234.6°C to 243.4°C for 500mW operation in 125°C moving air, from 266.7°C to 279.7°C for 662mW operation in 125°C moving air, and from 297.4°C to 313.0°C for 778mW operation in 125°C moving air. The specific value for TJ for each readout on an individual device was used in calculating the TC value used in the θC-A computations of Section 5.3 ($TC = TJ - \theta J\text{-}C \times P$).

θJ-A values were also calculated and are included in Tables 5.2 through 5.9. θJ-A was calculated from $\theta J\text{-}A = \frac{TJ - TA}{Power(P)} = \frac{\Delta VBE}{K \times P}$.

5.5 Verification of Case Temperature Measurements

To lend credence to the case temperature values determined by the experiments in Section 5.3 (Measurement of θC-A), several color dots of Detecto-Temp temperature-indicating paint were applied to selected points on the outside of the cases of the six test units just prior to their operation in an oven with 100°C moving air. The physical layout of the color dots and their color-change temperatures are shown in Figure 8. Following operation at each power level (500mW, 662mW, and 778mW), the oven door was opened briefly and the paint dots examined for color changes. The observed color changes are presented on Page 1 of Table 5.11. The measured and calculated case temperatures were then compared with the observed paint dot color changes. The results of these comparisons are shown on Page 2 of Table 5.11. Only one of the fifteen measured case temperatures was verified, but seventeen of the eighteen calculated TC values were verified. This gave additional support to the previous decision that the calculated case temperatures were more accurate than the measured ones.

TOP VIEW

2N2222 TO-18 CASE

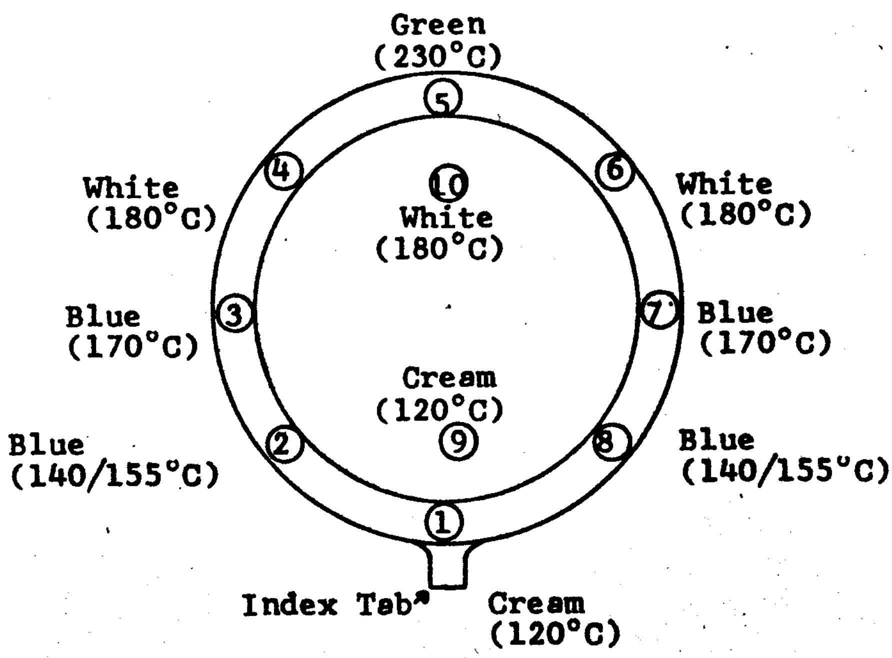


FIGURE 8 DETECTO-TEMP PAINT DOT LAYOUT FOR TEST D01

THERMAL RESISTANCE DATA

TABLE 5.1

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Test for measuring θC-A with 3 mil copper-constantan thermocouples bonded* to case.

	1st Readout Still Ambient Air				2nd Readout Still Ambient Air				3rd Readout Moving Ambient Air		
S/N	ΔVBE at 500mw	TA	TC		ΔVBE at 500mw	TA	TC		ΔVBE at 500mw	TA	TC
UNIT	mv	°C	°C		mv	°C	°C		mv	°C	°C
MINIMUM											
MAXIMUM											
373	---	---	---		---	---	---		---	---	---
374	---	---	---		---	---	---		---	---	---
375	---	---	---		---	---	---		---	---	---
376	250	24.4	103.6		249	24.7	103.7		188	25.5	73.0
377	259	24.5	107.8		290	24.6	117.3		193	25.4	72.7
278	290	24.4	129.4		300	24.7	129.6		197	25.5	77.2
DATE	12-10	12-10	12-10		12-13	12-13	12-13		12-14	12-14	12-14
STATION	Bench	Bench	Bench		Bench	Bench	Bench		Bench	Bench	Bench
INSP. STAMP											

REMARKS IC=40mA, VCE=12.5volts, I sense=2.0mA on all readout
(*) Bonded to index tab on flange with Eastman 910 cement.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 5.1 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP RKY 098 SUBGROUP D01

Test for measuring θC-A with 3 mil copper-constantan thermocouples bonded* to case.

	4th Readout Moving Air at 100°C				5th Readout Moving Ambient Air				6th Readout Still Ambient Air		
S/N	ΔVBE at 500mw	TA	TC		ΔVBE at 500mw	TA	TC		ΔVBE at 500mw	TA	TC
UNIT	mv	°C	°C		mv	°C	°C		mv	°C	°C
MINIMUM											
MAXIMUM											
373	---	---	---		202	25.2	71.8		310	24.8	144.0
374	---	---	---		199	24.7	76.4		292	24.9	139.9
375	---	---	---		200	25.0	76.3		326	24.9	130.5
376	186	100.3°	139.6		190	25.1	70.1		---	---	---
377	192	100.6°	139.9		192	25.0	66.2		---	---	---
378	189	102.5°	134.6		186	25.1	66.8		---	---	---
DATE	12-14	12-14	12-14		12-18	12-18	12-18		12-20	12-20	12-20
STATION	Bench	Bench	Bench		Bench	Bench	Bench		Bench	Bench	Bench
INSP. STAMP											

REMARKS IC=40mA, VCE=12.5volts, I sense=2.0mA on all readouts. (*) Bonded to index tab on flange with Eastman 910 cement.

NAME
TITLE
DATE

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP Do1

TABLE 5.1 (Cont'd)

Test for measuring θC-A with 3 mil copper-constantan thermocouple bonded* to case.

	7th Readout-500mw Moving Air at 100°C 3 mil thermocouple bonded to case				8th Readout-662mw Moving Air at 100°C 3 mil thermocouple bonded				9th Readout-778mw Moving Air at 100°C Thermocouple bonded		
S/N	ΔVBE at 500mw	TA	TC(2)		ΔVBE at 662mw	TA	TC(2)		ΔVBE at 778mw	TA	TC(2)
UNIT	mv	°C	°C		mv	°C	°C		mv	°C	°C
MINIMUM											
MAXIMUM											
373	210	102.5	139.2		272	99.3	151.2		336	99.3	139.4(3)
374	201	102.5	145.7		265	99.3	152.6		330	100.2	(1)
375	202	103.1	146.2		268	99.7	148.7		318	99.7	160.8
376	193	102.6	140.0		259	99.7	148.9		310	99.4	156.0
377	196	103.1	136.4		261	99.7	143.5		312	100.3	150.9
378	190	100.5	136.1		257	97.4	141.7		318	98.0	141.4(3)
DATE	12-21	12-21	12-21		12-21	12-21	12-21		12-21	12-21	12-21
STATION	Bench	Bench	Bench		Bench	Bench	Bench		Bench	Bench	Bench
INSP. STAMP											

(1) Thermocouple came off at high temperature. were soldered on for later tests.

(2) Detecto-Temp paint dots were painted on the sides and top of the TO-18 case to determine maximum case temperatures reached during test.

(3) Data indicates thermocouple bond may have loosened.

REMARKS IC=40mA, VCE=12.5V, I sense=2.0mA on all readouts.
(*) Bonded to index tab on flange with Eastman 910 cement.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 5.1 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY098 SUBGROUP D01

Test for measuring θC-A with 3 mil copper-constantan thermocouple soldered to case.

	10th Readout Still Ambient Air 3 mil thermocouple soldered to case.					11th Readout Moving Ambient Air 3 mil thermocouple soldered to case.					
S/N	ΔVBE at 500mw	TA	TC			ΔVBE at 500mw	TA	TC			
UNIT	mv	°C	°C			mv	°C	°C			
MINIMUM											
MAXIMUM											
373	---	---	---			208	25.0	85.5			
374	---	---	---			210	25.0	96.2			
375	---	---	---			212	25.0	99.3			
376	273	25.0	126.8			215	25.0	95.0			
377	307	25.0	147.3			213	25.0	(1)			
378	289	25.0	137.1			212	25.0	101.5			
DATE	1-10	1-10	1-10			1-10	1-10	1-10			
STATION	Bench	Bench	Bench			Bench	Bench	Bench			
INSP. STAMP						Page 5-20					

(1) Thermocouple broke off during test.

REMARKS IC=40mA, VCE=12.5V, I sense=2.0mA on all readouts.

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

TABLE 5.1(Cont'd)

Test for measuring θC-A with 3 mil copper-constantan thermocouple soldered to case.

	12th Readout-500mw Moving Air at 125°C 3 mil thermocouple soldered to case				13th Readout-662mw Moving Air at 125°C 3 mil thermocouple soldered				14th Readout-778mw Moving Air at 125°C Thermocouples soldered		
S/N	ΔVBE at 500mw	TA	TC		ΔVBE at 662mw	TA	TC		ΔVBE at 778mw	TA	TC
UNIT	mv	°C	°C		mv	°C	°C		mv	°C	°C
MINIMUM											
MAXIMUM											
373	205	125.7	173.7		260	125.5	184.8		322	125.1	195.4
374	201	125.3	182.9		260	125.3	195.6		318	124.4	212.7
375	211	125.3	187.0		266	125.7	204.5		327	124.6	221.8
376	212	124.6	184.1		276	126.6	202.4		331	125.5	213.3
377	217	124.7	(1)		277	126.4	(1)		331	125.5	(1)
378	218	124.9	182.5		282	126.3	210.3		345	125.5	228.4
(1) Thermocouple broke off during test.											
DATE	1-10	1-10	1-10		1-10	1-10	1-10		1-10	1-10	1-10
STATION	Bench	Bench	Bench		Bench	Bench	Bench		Bench	Bench	Bench
INSP. STAMP						Page 5-21					

REMARKS All power levels are applied with VCE=12.5V and I sense=2.0mA.

NAME
TITLE
DATE

THERMAL RESISTANCE DATA

TABLE 5.1 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Test for measuring θ_{C-A} with 3 mil copper-constantan thermocouple soldered to case.

15th Readout-500mw Still Ambient Air Thermocouple soldered on				16th Readout-500mw Moving Ambient Air Thermocouple soldered on				17th Readout-500mw Moving Air at 100°C Thermocouple soldered on			
S/N	ΔVBE at 500mw	TA	TC		ΔVBE at 500mw	TA	TC		ΔVBE at 500mw	TA	TC
UNIT	mv	°C	°C		mv	°C	°C		mv	°C	°C
MINIMUM											
MAXIMUM											
373	---	---	---		---	---	---		205	101.5	148.4
374	---	---	---		---	---	---		202	101.6	153.1
375	307	25.3	132.4		---	---	---		210	101.5	153.0
376	---	---	---		213	25.3	88.8		215	101.8	162.1
377	---	---	---		211	25.3	89.7		214	101.8	161.9
378	---	---	---		---	---	---		210	102.1	154.4
DATE	1-12	1-12	1-12		1-12	1-12	1-12		1-13	1-13	1-13
STATION	Bench	Bench	Bench		Bench	Bench	Bench		Bench	Bench	Bench
INSP. STAMP						Page 5-22					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 5.1 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Test for measuring θC-A with 3 mil copper-constantan thermocouple soldered to case.

	18th Readout-Water Bath 3 mil copper-constantan Thermocouple soldered on case				19th Readout-Water Bath 3 mil copper-constantan Thermocouple soldered on				20th Readout Copper-constantan Thermocouple check		
S/N	Null VBE (cold)	TC Cold Water	Null VBE (Hot)	TC Hot Water	Null VBE (Cold)	TC(1) Cold Water	Null VBE (Hot)	TC(1) Hot Water	TA Still Air	TC Cold Water	TC Hot Water
UNIT	Volts	°C	volts	°C	Volts	°C	Volts	°C	°C	°C	°C
MINIMUM											
MAXIMUM											
373	.703	23.4	.602	86.4	.708	24.2	.608	82.4	22.64	21.35	81.52
374	.699	23.1	.599	87.4	.701	24.2	.600	82.7	22.64	21.61	81.52
375	.704	23.6	.598	90.8	.711	24.1	.601	82.6	21.87	20.83	81.29
376	.697	23.9	.588	93.1	---	---	---	---	21.87	21.09	81.29
377	.695	23.9	.588	90.6	---	---	---	---	---	---	---
378	.691	24.2	.585	90.4	---	---	---	---	---	---	---
SIB	Standards Lab Copper-constantan thermocouple: (with ice bath reference junction)						---	---	24.76	24.27	80.96
S3M	3 mil copper-constantan thermocouple:					---	---	---	21.87	20.83	81.29
GLT	Laboratory Glass Thermometer:					---	---	---	24.2	23.5	79.1
DATE	1-13	1-13	1-13	1-13	1-14	1-14	1-14	1-14	1-17	1-17	1-17
STATION	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP						Page 5-23					

REMARKS (1) Standards Lab thermocouple used to measure water bath temperatures.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 5.1 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Test for measuring ΘC-A with 3 mil copper-constantan thermocouple soldered to case.

21st Readout

S/N	VBE Null (cold)		(1) TC Cold Water		(2) TC Cold Water		VBE Null (Hot)		(1) TC Hot Water		(2) TC Hot Water
UNIT	Volts		°C		°C		Volts		°C		°C
MINIMUM											
MAXIMUM											
373	.708		21.40		24.51		.607		80.15		78.51
374	---		---		---		---		---		---
375	---		---		---		---		---		---
376	---		---		---		---		---		---
377	---		---		---		---		---		---
DATE	1-17		1-17		1-17		1-17		1-17		1-17
STATION	Bench		Bench		Bench		Bench		Bench		Bench
INSP. STAMP											

(1) 3 mil copper-constantan thermocouple soldered to TO-18 case.

(2) Standards Lab copper-constantan thermocouple (with ice bath reference junction)

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 5.1(Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Test for measuring θC-A with 3 mil copper-constantan thermocouple soldered to case.

	22nd Readout								23rd Readout Case in Water Bath		
		(1)	(2)			(1)	(2)			(1)	(2)
S/N	Null VBE (cold)	TC Cold Water	TC Cold Water		Null VBE (Hot)	TC Hot Water	TC Hot Water		ΔVBE at 500mw	TC	TC
UNIT	Volts	°C	°C		Volts	°C	°C		Volts	°C	°C
MINIMUM											
MAXIMUM											
373	.709	22.2	24.0		.597	89.6	86.2		100	23.0	25.3
374	.701	22.4	24.5		.593	87.3	84.9		101	23.0	25.0
375	---	---	---		---	---	---		---	---	---
376	.703	22.2	23.8		.591	88.3	84.9		108	22.7	25.0
377	.701	22.7	25.0		.590	87.3	86.0		107	22.7	25.0
378	.700	22.7	24.3		.596	86.4	85.1		106	22.7	25.0
DATE	1-22	1-22	1-22		1-22	1-22	1-22		1-22	1-22	1-22
STATION	Bench	Bench	Bench		Bench	Bench	Bench		Bench	Bench	Bench
INSP. STAMP											

(1) 3 mil copper-constantan thermocouple soldered to TO-18 case.

(2) Standards Lab copper-constantan thermocouple (with ice bath reference junction)

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE DATA

TABLE 5.1 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Test for measuring θC-A with 3 mil copper-constantan thermocouple soldered to case.

24th Readout-500mw
Still Ambient Air

	(1)		(2)							
	ΔVBE at 500mw		TA Still Air		TC at 500mw					
UNIT	mv		°C		°C					
MINIMUM										
MAXIMUM										
373	305		25.25		121.7					
374	257		26.00		117.7					
375	---		---		---					
376	291		26.75		138.3					
377	285		26.00		126.5					
378	292		26.25		132.3					
DATE	1-22		1-22		1-22		1-22		1-22	
STATION	Bench		Bench		Bench		Bench		Bench	
INSP. STAMP										

(1) Standards Lab copper-constantan thermocouple (with ice bath reference junction)

(2) 3 mil copper-constantan thermocouple soldered to TO-18 case.

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 5.1 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Test for measuring θC-A with 3 mil copper-constantan thermocouple soldered to case.

	25th Readout-500mw Moving Air at 100°C				26th Readout-662mw Moving Air at 100°C				27th Readout-778mw Moving Air at 100°C		
S/N	ΔVBE at 500mw	TA	TC		ΔVBE at 662mw	TA	TC		ΔVBE at 778mw	TA	TC
UNIT	mv	°C	°C		mv	°C	°C		mv	°C	°C
MINIMUM											
MAXIMUM											
373	200	97.9	157.2		263	97.3	177.9		341	97.9	190.5
374	191	97.3	153.7		265	97.0	172.8		309	97.7	184.3
375	---	---	---		---	---	---		---	---	---
376	210	97.9	150.3		270	97.0	175.8		331	97.5	177.5
377	213	97.3	151.1		268	97.5	175.1		338	97.3	173.6
378	208	97.9	150.7		265	97.3	176.6		328	97.9	174.0
DATE	1-22	1-22	1-22		1-22	1-22	1-22		1-22	1-22	1-22
STATION	Bench	Bench	Bench		Bench	Bench	Bench		Bench	Bench	Bench
INSP. STAMP						Page 5-27					

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE PROGRAM
MEASUREMENT OF θJ-A
(CALCULATED DATA)

TABLE 5.2

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Calculated values of TJ & TC plus comparison of calculated and measured values of TC(1)

		R/O	1st			2nd			6th		
		Data	Calc.	Meas.	Calc.	Calc.	Meas.	Calc.	Calc.	Meas.	Calc.
S/N	θJ-C at 500mw		TJ	TC	TC	TJ	TC	TC	TJ	TC	TC
UNIT	°c/w		°C	°C	°C	°C	°C	°C	°C	°C	°C
MINIMUM											
MAXIMUM											
373	109		---	---	---	---	---	---	193.3	144.0	139.3
Δ%M-C(2)					---			---			3.3
374	104		---	---	---	---	---	---	183.7	139.9	130.7
Δ%M-C					---			---			6.6
375	115		---	---	---	---	---	---	202.1	130.5	144.6
Δ%M-C					---			---			-10.8
376	117		164.3	103.6	105.3	164.2	103.7	105.2	---	---	---
Δ%M-C					-1.6			-1.5			---
377	113		169.5	102.8	112.5	188.4	117.3	131.4	---	---	---
Δ%M-C					-9.4			-12.0			---
378	117		187.7	129.4	130.2	193.4	129.6	135.9	---	---	---
Δ%M-C					-0.6			-4.9			---

(1) All data taken at 500mw in still ambient air with 3 mil thermocouple bonded to case with Eastman 910 cement.

(2) % difference in measured value (M) and calculated value (C) calculated $\frac{M-C}{M}$ X 100

DATE	12-6			12-10			12-13			12-20
STATION	H0-01			Bench			Bench			Bench
INSP. STAMP										

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

TABLE 5.2 (Cont'd)

Calculated values of TJ & TC plus comparison of calculated and measured values of TC[1].

	10th			15th			24th				MEAN VALUE
	Calc.	Meas.	Calc.	Calc.	Meas.	Calc.	Calc.	Meas.	Calc.		
S/N	TJ	TC	TC	TJ	TC	TC	TJ	TC	TC		Δ TC (M-C)
UNIT	°C	°C	°C	°C	°C	°C	°C	°C	°C		%
MINIMUM											
MAXIMUM											
373	---	---	---	---	---	---	191.1	121.7	136.6		
Δ%M-C			---			---			-12.2		7.8
374	---	---	---	---	---	---	165.7	117.7	113.7		
Δ%M-C			---			---			3.4		5.0
375	---	---	---	192.2	132.4	134.7	---	---	---		
Δ%M-C			---			-1.7			---		6.3
376	173.5	126.8	114.5	---	---	---	184.4	138.3	125.9		
Δ%M-C			9.7			---			9.0		5.5
377	192.0	147.3	135.0	---	---	---	180.9	126.5	124.4		
Δ%M-C			8.4			---			1.7		7.9
378	172.1	137.1	114.6	---	---	---	185.1	132.3	126.6		
Δ%M-C			16.4			---			4.3		6.6
									MEAN VALUE:		6.5
DATE		1-10			1-12			1-22			
STATION		Bench			Bench			Bench			
INSP. STAMP											

(1) All data taken at 500mw in still ambient air with 3 mil thermocouples soldered to case.

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. ...

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

TABLE 5.2 (Cont'd)

Computation of θJ-A and θC-A values for 500mw operation in still ambient air.

Mean values for individual units.						From Meas. Values	From Calc. Values	From Meas. Values	From Calc. Values	% between Meas. & Calc. Values	
	Calc.	Meas.	Calc.	Meas.							
S/N	TJ	TC	TC	TA		θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°C	°C	°C	°C		°c/w	°c/w	°c/w	°c/w	%	%
MINIMUM											
MAXIMUM											
373	192.2	132.9	138.0	25.1		---	334.2	215.6	225.8	---	4.7
374	174.7	128.8	122.2	25.5		---	298.4	206.6	193.4	---	6.4
375	197.2	131.5	139.7	25.1		---	344.2	212.8	229.2	---	7.7
376	171.6	118.1	112.7	25.2		---	292.8	185.8	175.0	---	5.8
377	182.7	123.5	125.8	25.0		---	315.4	197.0	201.6	---	2.3
378	184.6	132.1	126.8	25.1		---	319.0	214.0	203.4	---	5.0
						MEAN VALUE:		205.3	204.7	---	5.3
DATE											
STATION											
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE PROGRAM
MEASUREMENT OF θJ-A
(CALCULATED DATA)

TABLE 5.3

DEVICE TYPE 2N2222
SPEC. REV. NO. Proj. 1130 (JPL)
LOT NUMBER 544 (SL 3-05)
GROUP REY 098 SUBGROUP D01

Calculation of TJ & TC plus comparison of calculated & measured values of TC (1)

		R/O	3rd				5th				
		DATA	CALC.	MEAS.	CALC.		CALC.	MEAS.	CALC.		
S/N	θ JC at 500mW		TJ	TC	TC		TJ	TC	TC		
UNIT	°C/W		°C	°C	°C		°C	°C	°C		
MINIMUM											
MAXIMUM											
373	109		--	--	--		142.5	71.8	88.5		
Δ%M-C (2)					--				-23.3		
374	104		--	--	--		135.1	76.4	82.1		
Δ%M-C					--				-7.5		
375	115		--	--	--		138.0	76.3	80.0		
Δ%M-C					--				-4.9		
376	117		135.2	73.0	76.2		134.6	70.1	76.1		
Δ%M-C					-4.4				-8.6		
377	113		137.6	72.7	80.6		135.7	66.2	78.7		
Δ%M-C					-10.9				-18.9		
378	117		139.7	77.2	83.2		133.4	66.8	75.9		
Δ%M-C					- 7.8				-13.6		

(1) All data taken at 500mW in moving ambient air with 3 mil thermocouple bonded to case with Eastman 910 cement.

(2) % Difference in Measured Value (M) and Calculated Value (c) calculated $\frac{M-C}{M}$ X 100.

DATE	12-6			12-14				12-18			
STATION	HO-01			Bench				Bench			
INSP. STAMP						Page 5-31					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

TABLE 5.3 (Continued)

DEVICE TYPE
SPEC. REV. NO.
LOT NUMBER
GROUP SUBGROUP

Calculation of TJ & TC Plus comparison of calculated & measured values of TC (1)

	R/O	11th				16th				Mean	
	Data	Calc.	Meas.	Calc.		Calc.	Meas.	Calc.		Value	
S/N		TJ	TC	TC		TJ	TC	TC		ΔTC (M-C)	
UNIT		°C	°C	°C		°C	°C	°C		%	
MINIMUM											
MAXIMUM											
373		145.8	85.5	92.3		---	---	---			
Δ%M-C				-8.0				---		15.6	
374		147.4	96.2	96.4		---	---	---			
Δ%M-C				-0.2				---		3.8	
375		149.3	99.3	91.8		--	--	---			
Δ%M-C				7.6				---		6.3	
376		151.3	95.0	94.8		143.2	88.8	84.7			
Δ%M-C				0.2				4.6		4.5	
377		150.2	---	93.7		143.4	89.7	82.9			
Δ%M-C				--				7.60		12.5	
378		149.8	101.5	93.3		--	--	--			
Δ%M-C				8.1				--		9.8	
								MEAN VALUE:		8.8	
(1)	All data taken at 500mW in moving ambient air with 3 Mil thermocouple soldered to case.										
DATE			1-10				1-12				
STATION			Bench				Bench				
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

TABLE 5.3 (Continued)

DEVICE TYPE
SPEC. REV. NO.
LOT NUMBER
GROUP SUBGROUP

Computation of θJ-A and θC-A Values for 500mW Operation in moving ambient air.

Mean values for individual units						From Meas. Values	From Calc. Values	From Meas. Values	From Calc. Values	Δ% Between Meas.& Calc. Values	
	Calc.	Meas.	Calc.	Meas.							
S/N	TJ	TC	TC	TA		θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°C	°C	°C	°C		°C/W	°C/W	°C/W	°C/W	%	%
MINIMUM											
MAXIMUM											
373	144.2	78.7	90.4	25.1		---	238.2	107.2	130.6	---	21.8
374	141.3	86.3	89.3	24.9		---	232.8	122.8	128.8	---	4.9
375	143.7	87.8	85.9	25.0		---	237.4	125.6	121.8	---	3.0
376	141.1	81.7	83.0	25.2		---	231.8	113.0	115.6	---	2.3
377	141.7	76.2	84.0	25.2		---	233.0	102.0	117.6	---	15.3
378	141.0	81.8	84.1	25.2		---	231.6	113.2	117.8	---	4.1
						MEAN VALUE:		114.0	122.0	---	8.6
DATE											
STATION											
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1076

TABLE 5.4

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Calculated values of TJ & TC plus comparison of calculated & measure values of TC(1).

		R/O	4th				7th				
		DATA	Calc.	Meas.	Calc.		Calc.	Meas.	Calc.		
S/N	θJ-C at 500mw		TJ	TC	TC		TJ	TC	TC		
UNIT	°c/w		°c	°c	°c		°c	°c	°c		
MINIMUM											
MAXIMUM											
373	109		---	---	---		216.5	139.2	162.5		
Δ%M-C(2)					---				-16.7		
374	104		---	---	---		212.2	145.7	159.2		
Δ%M-C					---				-9.3		
375	115		---	---	---		210.6	146.2	153.1		
Δ%M-C					---				-4.7		
376	117		200.4	139.6	141.4		207.1	140.0	148.1		
Δ%M-C					-1.3				-5.8		
377	113		205.0	139.9	148.0		208.7	136.4	151.7		
Δ%M-C					-5.8				-11.2		
378	117		205.7	134.6	149.2		206.0	136.1	148.5		
Δ%M-C					-10.9				-9.1		

(1) All data taken at 500mw in moving 100°C air with 3 mil thermocouple bonded to case with Eastman 910 cement.

(2) % difference in measured value (M) and calculated value (C) calculated $\frac{M-C}{M}$ X 100.

DATE	12-6			12-14			12-21			
STATION	H0-01			Bench			Bench			
INSP. STAMP										

REMARKS

NAME
TITLE
DATE

TABLE 5.4 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Calculated values of TJ & TC plus comparison of calculated and measured values of TC(1).

	R/O	17th				25th				Mean	
	Data	Calc.	Meas.	Calc.		Calc.	Meas.	Calc.		Value	
S/N		TJ	TC	TC		TJ	TC	TC		ΔTC (M-C)	
UNIT		°C	°C	°C		°C	°C	°C		%	
MINIMUM											
MAXIMUM											
373		213.0	148.4	158.5		206.6	157.2	152.1			
Δ%M-C				-6.8				3.3		8.9	
374		211.4	153.1	159.4		201.1	153.7	149.1			
Δ%M-C				-4.1				3.0		5.5	
375		215.7	153.0	158.2		---	---	---			
Δ%M-C				-3.4				---		4.1	
376		218.8	162.1	160.3		212.1	150.3	153.6			
Δ%M-C				1.1				-2.2		2.6	
377		218.2	161.9	161.7		203.1	151.1	146.6			
Δ%M-C				0.1				3.0		5.0	
378		216.3	154.4	157.8		211.0	150.7	152.5			
Δ%M-C				-2.2				-1.2		5.8	
								MEAN VALUE:		5.3	
(1)	All data taken at 500mw in moving 100°C air with 3 mil thermocouple soldered to case.										
DATE			1-13				1-22				
STATION			Bench				Bench				
INSP. STAMP						Page 5-35					

REMARKS

NAME
TITLE
DATE

TABLE 5.4 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Computation of θJ-A and θC-A values for 500mw operation in moving 100°C air.

Mean values for individual units	Calc.	Meas.	Calc.	Meas.		From Meas. Values	From Calc. Values	From Meas. Values	From Calc. Values	Δ% between Meas. & Calc. Values	
S/N	TJ	TC	TC	TA		θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°C	°C	°C	°C		°c/w	°c/w	°c/w	°c/w	%	%
MINIMUM											
MAXIMUM											
373	212.0	148.3	157.7	100.6		---	222.8	95.4	114.2	---	19.7
374	208.2	150.8	155.9	100.5		---	215.4	100.6	110.8	---	10.1
375	213.2	149.6	155.7	102.3		---	221.8	94.6	106.8	---	12.9
376	209.6	148.0	150.9	100.7		---	217.8	94.6	100.4	---	6.9
377	208.8	147.3	152.0	100.7		---	216.2	93.2	102.6	---	10.1
378	209.8	144.0	152.0	100.8		---	218.0	86.4	102.4	---	18.5
						MEAN VALUE:		94.1	106.2	---	12.9
DATE											
STATION											
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

THERMAL RESISTANCE PROGRAM
MEASUREMENT OF θJ-A
(CALCULATED DATA)

TABLE 5.5

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ.1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Calculation of TJ & TC plus comparison of calculated and measured values of TC(1).

		R/O	8th				26th				MEAN
		DATA	CALC.	MEAS.	CALC.		CALC.	MEAS.	CALC.		VALUE
S/N	θJ-C at 500mw		TJ	TC	TC		TJ	TC	TC		Δ TC (M-C)
UNIT	°c/w		°C	°C	°C		°C	°C	°C		%
MINIMUM											
MAXIMUM											
373	109		245.2	151.2	173.7		240.3	177.9	168.1		
Δ %M-C(2)					14.9				5.5		10.2
374	104		241.7	152.6	171.5		241.0	172.8	172.2		
Δ %M-C					12.4				0.4		6.4
375	115		243.9	148.7	167.7		---	---	---		
Δ %M-C					-12.8				---		12.8
376	117		239.4	148.9	161.3		243.8	175.8	166.4		
Δ %M-C					-8.3				5.4		6.9
377	113		241.0	143.5	165.6		243.3	175.1	168.5		
Δ %M-C					-15.4				3.8		9.6
378	117		237.5	141.7	161.3		241.4	176.6	164.0		
Δ %M-C					-13.8				7.1		10.5
									MEAN VALUE:		9.4

(1) All data taken at 662mw in moving 100°C air. 8th Readout has thermocouple bonded to case with Eastman 910 cement. 26th Readout has thermocouple soldered to case.

(2) % difference of measured value (M) and calculated value (C) calculated $\frac{M-C}{M} \times 100$.

DATE	12-6			12-21			1-22	
STATION	H0-01			Bench			Bench	
INSP. STAMP								

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

DEVICE TYPE ______
SPEC. REV. NO. ______
LOT NUMBER ______

TABLE 5.5 (Cont'd)

GROUP ______ SUBGROUP ______

Computation of θJ-A and θC-A values for 662 mw operation in moving 100°C air.

Mean values for individual units.						From Meas. values	From Calc. values	From Meas. values	From Calc. values	Δ% between meas. & calc. values.	
	Calc.	Meas.	Calc.	Meas.							
S/N	TJ	TC	TC	TA		θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°C	°C	°C	°C		°c/w	°c/w	°c/w	°c/w	%	%
MINIMUM											
MAXIMUM											
373	242.8	164.6	170.9	98.3		--	218.3	100.2	109.7	--	- 9.5
374	241.4	162.7	171.9	98.2		--	216.3	97.4	111.3	--	-14.3
375	243.9	---	167.7	99.7		--	217.8	---	102.7	--	---
376	241.6	102.4	163.9	98.4		--	216.3	96.7	98.9	--	- 2.3
377	242.2	159.3	167.1	98.6		--	216.9	91.7	103.5	--	-12.9
378	239.5	159.2	162.7	97.4		--	214.8	93.4	98.6	--	-5.6
					MEAN VALUE:			95.9	104.1	--	8.9
DATE											
STATION											
INSP. STAMP											

REMARKS

NAME ______
TITLE ______
DATE ______

MOTOROLA FORM NO. ...

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE PROGRAM
MEASUREMENT OF θJ-A
(CALCULATED DATA)

TABLE 5.6

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Calculation of TJ & TC plus comparison of calculated and measured values of TC(1).

		R/O	9th				27th				MEAN VALUE
		DATA	CALC.	MEAS.	CALC.		CALC.	MEAS.	CALC.		
S/N	θJ-C at 500mw		TJ	TC	TC		TJ	TC	TC		ΔTC (M-C)
UNIT	°c/w		°C	°C	°C		°C	°C	°C		%
MINIMUM											
MAXIMUM											
373	109		281.8	139.1*	197.0		283.1	190.5	198.3		
Δ%M-C(2)					---				-4.1		4.1
374	104		279.5	---	198.6		265.6	184.3	184.7		
Δ%M-C					---				-0.2		0.2
375	115		272.5	160.8	183.0		---	---	---		
Δ%M-C					-13.8						13.8
376	117		267.8	156.0	176.8		277.3	177.5	186.3		
Δ%M-C					-13.3				-5.0		9.1
377	113		269.8	150.9	181.8		280.8	173.6	192.8		
Δ%M-C					-20.5				-11.1		15.8
378	117		270.8	141.4*	179.8		276.0	174.0	185.0		
Δ%M-C					---				-6.3		6.3
									MEAN VALUE:		8.2

(1) All data taken at <u>778mw</u> is moving 100°C air. 9th Readout has thermocouple bonded to case with Eastman 910 cement. 27th Readout has thermocouple <u>soldered</u> to case.

(2) % difference of measured value (M) and Calculated value (C) calculated $\frac{M-C}{M}$ X 100

DATE	12-6		12-31			1-22	
STATION	H0-01		Bench			Bench	
INSP. STAMP							

REMARKS (*) Data indicates thermocouple bond may have loosened. Not used in calculation of mean values

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

DEVICE TYPE
SPEC. REV. NO.
LOT NUMBER
GROUP SUBGROUP

TABLE 5.6 (Cont'd)

Computation of θJ-A and θC-A values for 778mw operation in moving air 100°C.

Mean Values for individual units.						From Meas. Values	From Calc. Values	From Meas. Values	From Calc. Values	Δ% between Meas. & Calc. Values	
	Calc.	Meas.	Calc.	Meas.							
S/N	TJ	TC (1)	TC	TA		θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°C	°C	°C	°C		°c/w	°c/w	°c/w	°c/w	%	%
MINIMUM											
MAXIMUM											
373	282.5	190.5	197.7	98.6		--	236.5	118.1	127.4	---	7.9
374	272.6	184.3	191.7	99.0		--	223.1	109.6	119.1	---	8.7
375	272.5	---	183.0	99.7		--	222.1	---	107.1	---	---
376	272.6	177.5	181.6	98.5		--	224.0	101.5	106.9	---	5.3
377	275.3	173.6	187.3	98.8		--	227.0	96.2	113.8	---	18.3
378	273.4	174.0	182.4	98.0			225.6	97.7	108.5	---	11.1
						MEAN VALUE:		104.5	113.9	---	10.3
(1)	Values from 27th R/O only - thermocouples appeared to be loose or becoming loose during 9th R/O with Eastman "910" bonding.										
DATE											
STATION											
INSP. STAMP											

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

THERMAL RESISTANCE PROGRAM
MEASUREMENT OF θJ-A
(CALCULATED DATA)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)

TABLE 5.7

GROUP REY 098 SUBGROUP D01

Calculated values of TJ & TC - Comparison of measured & calculated values - computation of θJ-A & θC-A

	R/O	12th - 500mw (1)				From Meas. Values	From Calc. Values	From Meas. Values	From Calc. Values	Δ% between Meas. & Calc. Values	
	DATA	Calc.	Meas.	Calc.	Meas.						
S/N	θJ-C at 500mw	TJ	TC	TC	TA	θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°c/w	°C	°C	°C	°C	°c/w	°c/w	°c/w	°c/w	%	%
MINIMUM											
MAXIMUM											
373	109	237.2	173.7 (*)	183.2	125.7	---	223.0	---	115.0	---	---
Δ%M-C (2)				---							
374	104	234.6	182.9	181.6	125.3	---	218.6	115.2	112.6	---	2.3
Δ%M-C				0.7							
375	115	240.0	187.0	182.5	125.3	---	229.4	123.4	114.4	---	7.3
Δ%M-C				2.4							
376	117	239.9	184.1	180.9	124.6	---	230.6	119.0	112.6	---	5.4
Δ%M-C				1.7							
377	113	243.0	---	186.0	124.7	---	236.6	---	122.6	---	---
Δ%M-C				---							
378	117	243.4	182.5	185.9	124.9	---	237.0	115.2	122.0	---	5.9
Δ%M-C				-1.9							
						MEAN VALUE:		118.2	116.5	---	5.2

(1) All data taken in moving air at 125°C with 3 mil thermocouple soldered to case.

(2) % difference of measured values (M) and calculated values (C) calculated $\frac{M-C}{M}$ X 100

DATE	12-6		1-10	
STATION	HO-01		Bench	
INSP. STAMP				Page 5-41

REMARKS (*) Apparent measurement error - Not used in calculations.

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE PROGRAM
MEASUREMENT OF θJ-A
(CALCULATED DATA)

TABLE 5.8

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Calculated values of TJ & TC - Comparison of measured and calculated values-computation of θJ-A & θC-A											
	R/O	13th - 662mw (1)				From	From	From	From	Δ% between	
	DATA	Calc.	Meas.	Calc.	Meas.	Meas. Values	Calc. Values	Meas. Values	Calc. Values	Meas. & Calc. Values	
S/N	θJ-C at 500mw	TJ	TC	TC	TA	θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°c/w	°C	°C	°C	°C	°c/w	°c/w	°c/w	°c/w	%	%
MINIMUM											
MAXIMUM											
373	109	266.9	184.8 (*)	195.4	125.5	---	213.6	---	105.6	---	---
Δ%M-C (2)				---							
374	104	266.7	195.6	196.5	125.3	---	213.6	106.2	107.6	---	13.2
Δ%M-C				-0.5							
375	115	270.3	204.5	194.1	125.7	---	218.4	119.0	103.3	---	13.2
Δ%M-C				5.1							
376	117	276.6	202.4	198.5	126.6	---	226.6	114.5	108.6	---	5.2
Δ%M-C				1.9							
377	113	276.9	---	201.5	126.4	---	227.3	---	113.4	---	---
Δ%M-C				---							
378	117	279.7	210.3	203.5	126.3	---	231.6	126.7	116.5	---	8.1
Δ%M-C				3.2							
						MEAN VALUE:		116.6	109.2	---	9.9
(1)	All data taken in moving air at 125 °C with 3 mil thermocouple soldered to case.										
(2)	% difference of measured values (M) and Calculated values (C) calculated $\frac{M-C}{M} \times 100$										
DATE	12-6		1-10								
STATION	H0-01		Bench								
INSP. STAMP											

REMARKS (*) Apparent measurement error. Not used in calculations.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE PROGRAM
MEASUREMENT OF θJ-A
(CALCULATED DATA)

TABLE 5.9

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Calculated values of TJ & TC - Comparison of measured and calculated values-Computation of θJ-A & θC-A

	R/O DATA	14th - 778mw(1)				From Meas. Values	From Calc. Values	From Meas. Values	From Calc. Values	Δ% between Meas. & Calc. Values	
		Calc.	Meas.	Calc.	Meas.						
S/N	θJ-C at 500mw	TJ	TC	TC	TA	θJ-A	θJ-A	θC-A	θC-A	ΔθJ-A	ΔθC-A
UNIT	°c/w	°C	°C	°C	°C	°c/w	°c/w	°c/w	°c/w	%	%
MINIMUM											
MAXIMUM											
373	109	300.1	195.4(*)	214.9	125.1	---	224.9	---	115.4	---	---
Δ%M-C(2)				---							
374	104	297.4	212.7	216.5	124.4	---	222.4	113.5	118.4	---	4.3
Δ%M-C				-1.8							
375	115	302.5	221.8	211.9	124.6	---	228.7	124.9	112.2	---	11.0
Δ%M-C				4.5							
376	117	305.5	213.3	212.5	125.5	---	231.4	112.9	111.8	---	1.0
Δ%M-C				0.4							
377	113	305.5	---	215.6	125.5	---	231.4	---	115.8	---	---
Δ%M-C				---							
378	117	313.0	228.4	222.4	125.5	---	241.0	132.3	124.6	---	5.8
Δ %M-C				2.6							
						MEAN VALUE:		120.9	116.4	---	5.5

(1) All data taken in moving air at 125°C with 3 mil thermocouple soldered to case.

(2) % difference of measured value (M) and calculated value (C) calculated $\frac{M-C}{M}$ X 100

DATE	12-6		1-10	
STATION	HO-01		Bench	
INSP. STAMP				

REMARKS (*) Apparent measurement error. Not used in calculations.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

MOTOROLA INC.
Semiconductor
Products Division

THERMAL IMPEDANCE PROGRAM
MEASUREMENT OF θJ-A
(Calculated Data)

Table 5.10

DEVICE TYPE 2N2222
SPEC. REV. NO. Proj 1130 (JPL)
LOT NUMBER 544(SL3-05)
GROUP REY 098 SUBGROUP D01

Computation of temperature coefficient (K) - comparison of thermocouples & θJ-C Values

R/O	18th -"K" Factor			19th -"K" Factor			20th-Thermocouple (1)			23rd -θJ-C	
Data	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Meas.	Meas.	Meas.	Meas.	Calc.
S/N	Δ VBE	Δ TC	K	Δ VBE	Δ TC	K	Δ TA Amb. Air	Δ TW Cold Water	Δ TW Hot Water	θJ-C at 500mW	θJ-C at 500mW
UNIT	mV	°C	mv/°C	mV	°C	mV/°C	%	%	%	°C/W	°C/W
MINIMUM											
MAXIMUM											
373	101	63.0	-1.604	100	58.2	-1.718	8.6	12.0	-0.7	109	109
Δ%M-C (2)											0.0
374	100	64.3	-1.555	101	58.5	-1.726	8.6	11.0	-0.7	104	109
Δ%M-C											-4.8
375	106	67.2	-1.578	110	58.5	-1.880	11.7	14.2	-0.4	115	---
Δ%M-C											---
376	109	69.2	-1.575	--	--	--	11.7	13.1	-0.4	117	118
Δ%M-C											-0.9
377	107	66.7	-1.605	--	--	--	--	--	--	113	116
Δ%M-C											-2.7
378	106	66.2	-1.602	--	--	--	--	--	--	117	115
Δ%M-C											1.7
SIB	Standards Lab Cu-Const. "REFERENCE" thermocouple:						0.0	0.0	0.0	--	--
S3M	3 Mil Cu-Const. thermocouple-not bonded to case						11.7	14.2	-0.4	--	--
GLT	Laboratory thermometer:						2.3	3.2	2.3	--	--
(1)	Data shown is % deviation of readings of thermocouple or thermometer from "REFERENCE"										
DATE	1-13	1-13		1-14	1-14		1-17	1-17	1-17	12-6	1-22
STATION	Water	Water		Water	Water		Water	Water	Water	HO-01	Bench &
INSP. STAMP	Bath	Bath		Bath	Bath	Page 5-44	Bath	Bath	Bath		Water Bath

(2)% Difference of meas. value (m) & calc. value (c)
REMARKS calculated $\frac{M-C}{M}$ X 100.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

TABLE 5.10 (Continued)

DEVICE TYPE 2N2222
SPEC. REV. NO. Proj 1130 (JPL)
LOT NUMBER '544(SL3-05)
GROUP REY 098 SUBGROUP D01

Computation of temperature coefficient (K) - Comparison of thermocouples											
R/O Data	21st - "K" Factor						22nd - "K" Factor				
	Calc.	Calc.	Calc.	Calc.	Calc.		Calc.	Calc.	Calc.	Calc.	Calc.
S/N	ΔVBE	ΔTC (1)	ΔTC (2)	K (1)	K (2)		ΔVBE	ΔTC (1)	ΔTC (2)	K (1)	K (2)
UNIT	mV	°C	°C	mV/°C	mV/°C		mV	°C	°C	mV/°C	mV/°C
MINIMUM											
MAXIMUM											
373	101	58.8	54.00	-1.717	-1.870		112	67.4	62.2	-1.662	-1.800
Δ%(K) (3)					-8.2						-7.7
374	--	--	--	--	--		108	64.9	60.4	-1.664	-1.788
Δ%(K)					--						-6.9
375	--	--	--	--	--		--	--	--	--	--
Δ%(K)					--						--
376	--	--	--	--	--		112	66.1	61.1	-1.695	-1.832
Δ%(K)					--						-7.5
377	--	--	--	--	--		111	64.6	61.0	-1.718	-1.820
Δ%(K)					--						-5.6
378	--	--	--	--	--		104	63.7	60.8	-1.633	-1.710
Δ%(K)					--						-4.5
(1)	Data taken with 3 Mil copper-constantan thermocouple soldered to case.										
(2)	Data taken with Standards Lab copper-constant "REFERENCE" thermocouple (with										
	ice bath reference junction.)										
(3)	% Difference in "K" factor measured with different thermocouples; calculated										
	$\frac{K(2) - K(1)}{K(2)}$ X 100.										
DATE	1-17						1-22				
STATION	Water						Water				
INSP. STAMP	Bath					Page 5-45	Bath				

REMARKS

NAME
TITLE
DATE

MOTOROLA INC.
Semiconductor
Products Division

THERMAL RESISTANCE DATA

TABLE 5.11

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Use of Detecto-Temp paint to determine maximum case temperatures.

All tests performed in moving air at 100°C except
for 0mw condition which was performed at room ambient.

S/N	Power Level	Color Dot #1	Color Dot #2	Color Dot #3	Color Dot #4	Color Dot #5	Color Dot #6	Color Dot #7	Color Dot #8	Color Dot #9	Color Dot #10
UNIT	mw	color	color	color	color	color	color	color	color	color	color
MINIMUM	---	120°C	140°C 155°C	170°C	180°C	230°C	180°C	170°C	140°C 155°C	120°C	180°C
MAXIMUM											
All 6 units	0	cream	blue	blue	white	green	white	blue	blue	cream	white
373	500	cream	gray-green	medium gray	white	green	white	medium gray	gray-green	(1)	white
374	500	lilac	gray-green	medium gray	white	green	white	medium gray	gray-green	cream	white
375	500	cream	gray-green	medium gray	white	green	white	medium gray	gray-green	(1)	white
376	500	lilac	gray-green	medium gray	white	green	white	medium gray	gray-green	(1)	white
377	500	lilac	gray-green	medium gray	white	green	white	medium gray	gray-green	(1)	white
378	500	lilac	gray-green	medium gray	white	green	white	medium gray	gray-green	(1)	white
373	662	lilac	gray-green	medium gray	light yellow	green	light yellow	medium gray	gray-green	(1)	white
374	662	lilac	gray-green	medium gray	white	green	white	medium gray	gray-green	cream	yellow
375	662	cream	medium gray	medium gray	white	green	white	medium gray	medium gray	(1)	white
376	662	lilac	gray-green	medium gray	white	green	white	medium gray	gray-green	(1)	white
377	662	lilac	gray-green	medium gray	white	green	white	medium gray	gray-green	(1)	white
378	662	lilac	medium gray	medium gray	white	green	white	medium gray	medium gray	(1)	white
373	778	lilac	dark gray	dark gray	yellow	green	yellow	dark gray	dark gray	(1)	yellow
374	778	lilac	dark gray	dark gray	yellow	green	yellow	dark gray	dark gray	cream	yellow
375	778	cream	dark gray	dark gray	yellow	green	light yellow	dark gray	medium gray	(1)	white
376	778	lilac	gray-green	medium gray	light yellow	green	light yellow	medium gray	medium gray	(1)	white
377	778	lilac	medium gray	dark gray	white	green	white	medium gray	gray-green	(1)	light yellow
378	778	lilac	dark gray	dark gray	light yellow	green	white	medium gray	medium gray	(1)	white
(1)	Color dots did not adhere properly to the top of the TO-18 case-came off during test.										
DATE	12-21	12-21	12-21	12-21	12-21	12-21	12-21	12-21	12-21	12-21	12-21
STATION	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench	Bench
INSP. STAMP						Page 5-46					

REMARKS

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1078

MOTOROLA INC.
Semiconductor
Products Division

TABLE 5.11 (Cont'd)

DEVICE TYPE 2N2222
SPEC. REV. NO. PROJ. 1130 (JPL)
LOT NUMBER 544 (SL3-05)
GROUP REY 098 SUBGROUP D01

Verification of case temperature in moving 100°C air at three selected power levels.

		Case Temp.		Observed TC range based on change in color of Detecto-Temp paint.						Did color (1) change verify case temp.	
		Meas.	Calc.								
S/N	Power Level Applied	TC	TC	<120°C	>120°C <140°C	>140°C <155°C	>155°C <170°C	>170°C <180°C	>180°C <230°C	Meas. TC	Calc. TC
UNIT	mW	°C	°C	---	---	---	---	---	---	---	---
MINIMUM											
MAXIMUM											
373	500	139.2	162.5				X			No	Yes
374	500	145.7	159.2				X			No	Yes
375	500	146.2	153.1				X			No	Yes
376	500	140.0	148.1				X			No	No
377	500	136.4	151.7				X			No	Yes
378	500	136.1	148.5				X			No	No
373	662	151.2	173.7					X		No	Yes
374	662	152.6	171.5				X			Yes	Yes
375	662	148.7	167.7				X			No	Yes
376	662	148.9	161.3				X			No	Yes
377	662	143.5	165.6				X			No	Yes
378	662	141.7	161.3				X			No	Yes
373	778	---	197.0						X	--	Yes
374	778	---	198.6						X	--	Yes
375	778	160.8	183.0						X	No	Yes
376	778	156.0	176.8					X		No	Yes
377	778	150.9	181.8					X		No	Yes
378	778	---	179.8					X		--	Yes
DATE	12-21	12-21	12-21								
STATION	Bench	Bench	Bench								
INSP. STAMP						Page 5-47					

REMARKS (1) If meas. or calc. temp. was within 5°C of color change temp., it was considered verified.

NAME
TITLE
DATE

MOTOROLA FORM NO. SPD-1079

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The original intent of this program was for Motorola to refine an existing thermal resistance measuring technique and to determine its accuracy and repeatability, with the specific objectives of determining if the measurement technique was capable of $\pm$10% absolute accuracy and $\pm$5% repeatability.

After a thorough review of the data obtained, the results show that the objectives were successfully achieved.

Absolute accuracy verification by the thermocouple method demonstrated a "worst case" accuracy of 8.4% for a nominal $\theta J\text{-}C$ value of 100°C/W measured with TC of 25°C and 500mW. This would correspond to an error in TJ of 4.2°C (5.6%) at 75°C nominal TJ. The majority of this error is attributed to the HT cement used to bond the thermocouples; since, the successfully stitch-bonded device showed an absolute accuracy of 1.6%.

The temperature-indicating paint method utilizing "capped" devices demonstrated an absolute accuracy of $\pm$8.3% for a nominal $\theta J\text{-}C$ value of 100°C/W based on operation in 100°C moving air and 600mW. This would correspond to an error in TJ of $\pm$5°C ($\pm$2.1%) at 235°C nominal TJ. The accuracy in this instance is limited by the color-change temperature range of $\pm$5°C from the nominal value of 235°C.

The water bath method demonstrated an absolute accuracy of 1.6% for a nominal θJ-C of 124°C/W measured with TC of 25°C and 500mW.

The repeatability was demonstrated to be ±1.26%, which is well within the ±5% requirement in the JPL Accelerated Test Program.

θC-A values for the Motorola 2N2222 device were determined to be 205°C/W for still ambient air, 122°C/W for moving ambient air, and 110°C/W for moving 100°C air.

It was shown that θJ-C was independent of power level within the range of power levels normally experienced by the 2N2222, and that the value of θJ-C was not influenced significantly by removal of the cap.

6.2 Recommendations

Since the power levels proposed for the JPL Accelerated Life Test Program were based on a θJ-A value of 300°C/W, it is recommended that these values be recalculated using the value of 225°C/W. This is based on the value of 110°C/W for θC-A for 100°C moving air as determined from the Phase III tests and a nominal value of 115°C/W for θJ-C that was computed from the data taken during the repeatability verification experiment.

It is recommended that for any program requiring thermal resistance measurements on the 2N2222, a group of at least five devices be used as correlation samples for setting up tester HO-01 and for periodically monitoring the bench tester. This procedure will insure correlation with tester HO-01.

For any program requiring thermal resistance measurements on devices other than the 2N2222, it is recommended that the "K" factor be initially determined using the water bath technique and the $\theta C\text{-}A$ value be determined using the actual ambient air conditions and the bench tester.

7.0 KEY PERSONNEL

The following key personnel contributed to the Thermal Resistance Measurements Study Program during the course of the contract:

Kenneth W. Davidson - Mgr., Reliability Programs Dept.
Paul H. Greer - Project Manager
Jim Parch - Product Engineer, Silicon Devices
Nancy Ricketts - Sr. Data Analyst
William Roehr - Applications Engineer
Dr. O. B. Moan - Statistical Consultant (Arizona State U.)

APPENDIX

PHILCO

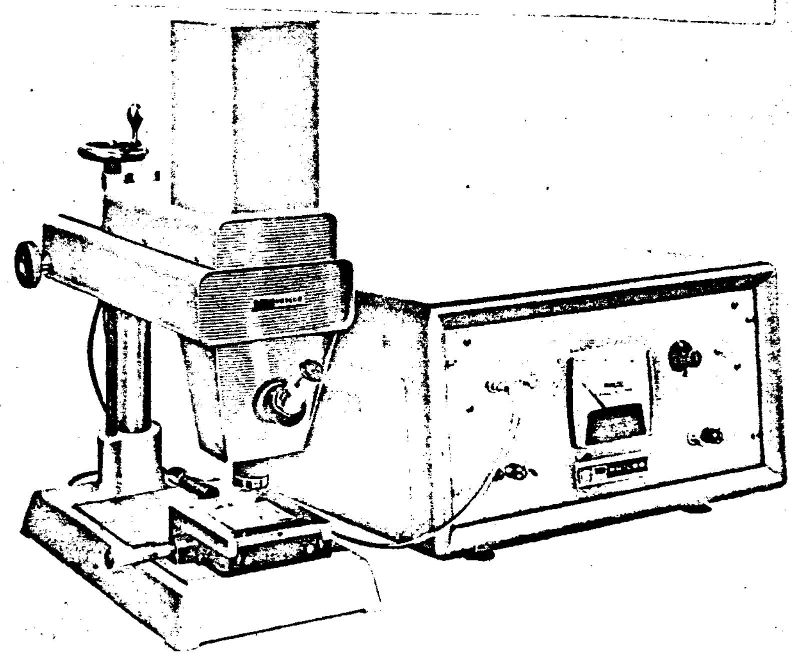
A SUBSIDIARY OF Ford Motor Company

LANSDALE DIVISION

THERMAL PLOTTER

FEATURES:

1. **High Spatial Resolution**—on the order of 2×10^{-6} sq. in.
2. **High Temperature Sensitivity**—on the order of ½°C.
3. **Wide Temperature Range**—from 30° C. up to several hundred °C.
4. **High Speed of Response**—sensor response is a few μsec.
5. **Non-contacting Method of Measurement**—does not alter the thermal profile of fine structures.
6. **Non-destructive Measurement Technique**
7. **Nitrogen Cooled InSb Cell**—8 hours continuous operation without refill.



Purpose and Advantages

Philco Thermal Plotter is an outstanding infrared sensing device used to analyze the temperature distribution of small structures, particularly the complex geometries of microcircuits. Philco Thermal Plotter may be used both as a design tool and as an aid in reliability and life testing. As a microcircuit design tool it enables rapid evaluation of power handling capabilities for a variety of operating conditions without extensive life-testing procedures. Used in reliability and life testing, the Thermal Plotter is capable of evaluation of large numbers of microcircuits and other small structures.

The Philco Thermal Plotter is the result of a search for an improved method of thermal evaluation of small structures. The commonly used techniques have many disadvantages: the use of thermocouples and of heat-sensitive films is slow and tedious; they lack the resolving power necessary to obtain complete information; their contact with the evaluated structure affects the heat distribution and causes inaccuracies.

Basic Design and Operation

The Philco Thermal Plotter is essentially a high-sensitivity infrared detector combined with a microscope. The heart of the system is an indium antimonide detector, a solid state device operating at liquid nitrogen temperatures. Attached to the detector is a dewar capable of an uninterrupted 8-hour operation. An optical system focusses the sensitive areas of the detector on the sample. The same system also provides visual observation capabilities by means of an additional eyepiece with crosshairs. The signal is chopped, amplified and demodulated by associated electronic circuitry, and displayed either on a built-in meter or on an external recorder, such as an X-Y plotter, strip chart recorder, or intensity-modulated long-persistence cathode ray tube.

In the manual plotter, the object is mounted on a micrometer substage and manually positioned while viewed through the eyepiece. A scanning feature can be added to the basic unit, thereby enabling the plotting of isotherms superimposed on an enlarged drawing of the object.

Automatic Plotting with X-Y Recorder

A method for the automatic plotting and display of thermal maps is available.

The sample is mounted on a substage and the micrometers are driven by two motors; the positional information is applied to an X-Y recorder, and the output from the IR cell is fed to the recorder's pen-lift mechanism.

By using a series of threshold circuits, curves of equal radiation can be plotted one at a time, thus providing a radiation map of the sample.

If a transparent enlarged drawing of the sample is superimposed on the X-Y plot, the emissivity of the various elements can be taken into consideration, enabling the conversion of the radiation map into a temperature plot.

High-Speed Dynamic Display on Cathode Ray Tube

Soon to be available will be a display method having the advantage of versatility and high speed. The sample is moved by means of a traverse mechanism while it is scanned in the other dimension with the use of a mirror-lens assembly rotating at high speed. The X-Y positional information is fed to a cathode ray tube display unit whose intensity is modulated by the IR cell's output. A number of threshold circuits can digitize the information to obtain plateaus of equal radiation.

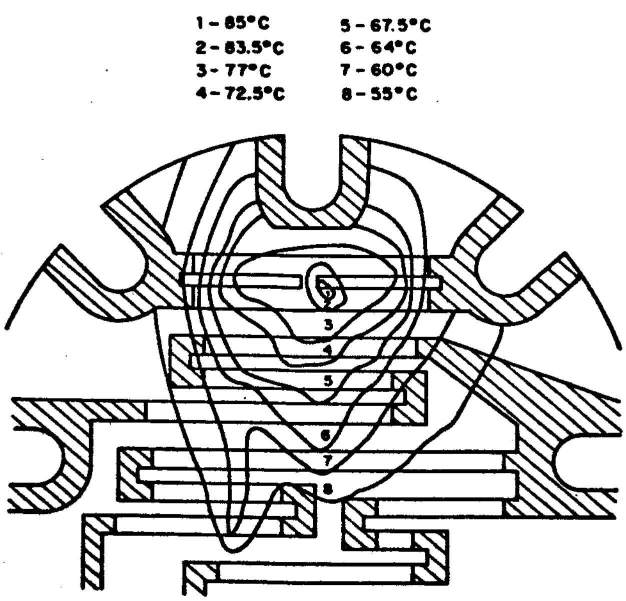
In this fashion a radiation plot can be displayed on the CRT face within a second's time and repeated about once per second. Using a long-persistence tube, the display can readily be viewed and also photographed for permanent record. Also, by changing the threshold settings, the plateaus to be viewed can easily be altered.

This method is particularly suited for design purposes due to its rapidity and ease of changing of settings. It can also be used as a quality control tool, either by visual observation or by providing alarm circuits to operate in conjunction with the threshold circuits, giving alarm or rejection signals if the radiation deviates in any area from the permissible setpoints.

For more information about the uses of the Thermal Plotter, see the following publications:

Walker, M., Roschen J., and Schlegel, E., IEEE Trans. Electron Dev., ED-10, No. 4, July 1963, p. 263.

Schlegel, E. S., Rev. Sci. Instr., 34, No. 4, April 1963, p. 360.



NOTE: ALL AREAS OUTSIDE OF ISOTHERM #8 WERE BELOW 55°C.

Figure 1

mal Profile of Tantalum Thin-Film Resistor Network (M = ~ 25 X)

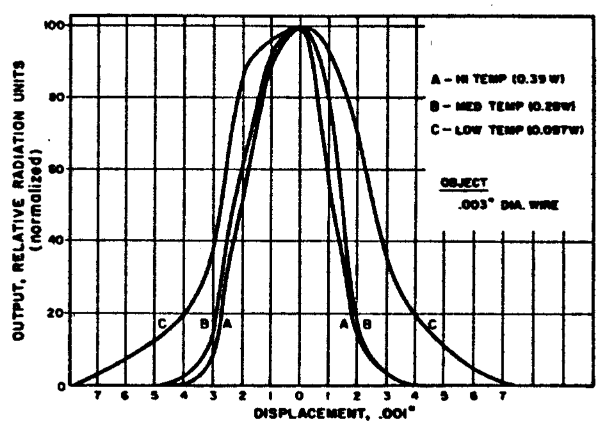


Figure 2—Philco Thermal Plotter Resolution Curves

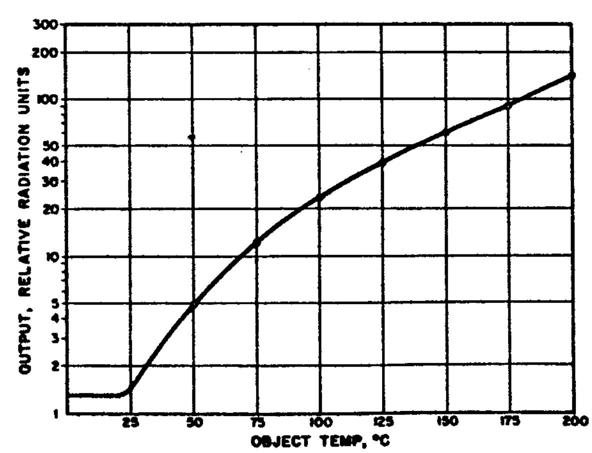


Figure 3—Philco Thermal Plotter Sensitivity Curve

MOTOROLA

NPN

2N2218-2N2219

2N2221-2N2222

PNP

2N2904-2N2905

2N2906-2N2907

SILICON ANNULAR STAR* TRANSISTORS

NPN

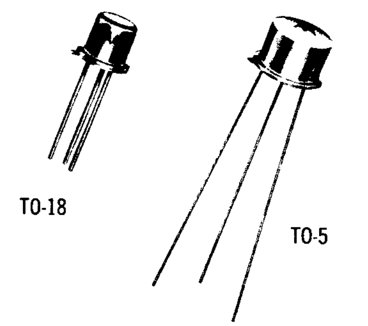
PNP

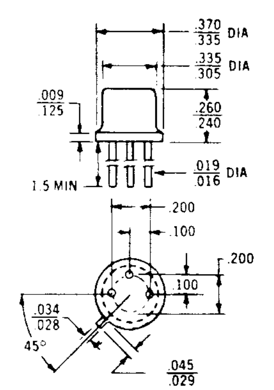
DESIGNED for COMPLEMENTARY HIGH-SPEED SWITCHING APPLICATIONS and DC to UHF AMPLIFIER CIRCUITS

- High Uniform Beta from 0.1 to 500 mA.
- High Voltage Ratings
- Similar Switching Characteristics
- Low $V_{CE(sat)}$ — 0.4 V at 150 mA Maximum

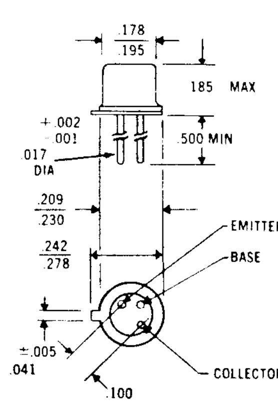
SILICON ANNULAR† EPITAXIAL COMPLEMENTARY SWITCHING TRANSISTORS

SEPTEMBER, 1963
DS 5057





TO-5 OUTLINE



TO-18 OUTLINE

ABSOLUTE MAXIMUM RATINGS

Characteristic	Symbol	NPN	PNP	Units
Collector - Base Voltage	V_{CBO}	60	60	Vdc
Collector - Emitter Voltage	V_{CEO}	30	40	Vdc
Emitter - Base Voltage	V_{EBO}	5	5	Vdc
Collector Current	I_C	800	600	mAdc
Total Device Dissipation @ 25°C Case Temperature	P_D			
To - 5: 2N2218, 2N2219		3		W
Derate Above 25°C		20		mW/°C
2N2904, 2N2905			3	W
Derate Above 25°C			17.2	mW/°C
To - 18: 2N2221, 2N2222		1.8		W
Derate Above 25°C		12		mW/°C
2N2906, 2N2907			1.8	W
Derate Above 25°C			10.3	mW/°C
Total Device Dissipation @ 25°C Ambient Temperature	P_D			
To - 5: 2N2218, 2N2219		0.8		W
Derate Above 25°C		5.33		mW/°C
2N2904, 2N2905			0.6	W
Derate Above 25°C			3.43	mW/°C
To - 18: 2N2221, 2N2222		0.5		W
Derate Above 25°C		3.33		mW/°C
2N2906, 2N2907			0.4	W
Derate Above 25°C			2.28	mW/°C
Operating Junction Temperature	T_J	-65 to +175	-65 to +200	°C
Storage Temperature	T_{stg}	-65 to +300	-65 to +300	°C

*Trademark of Motorola Inc.
†Manufactured by the annular process, Motorola patents applied for.

ELECTRICAL CHARACTERISTICS (At 25°C ambient unless otherwise noted)

Static Characteristic		Fig. No.	Symbol	Min	Max	Unit
Collector-Base Breakdown Voltage (I_C = 10 μAdc, I_E = 0)	All Types	---	BV_{CBO}	60	---	Vdc
Collector-Emitter Breakdown Voltage* (I_C = 10 mAdc, I_B = 0)	2N2218-19, 2N2221-22 2N2904 thru 2N2907	9	BV_{CEO}*	30 40	--- ---	Vdc
Emitter-Base Breakdown Voltage (I_E = 10 μAdc, I_C = 0)	All Types	---	BV_{EBO}	5	---	Vdc
Collector Cutoff Current (V_{CB} = 50 Vdc, I_E = 0) (V_{CB} = 50 Vdc, I_E = 0, T_A = 150°C)	2N2218-19, 2N2221-22 2N2904 thru 2N2907 2N2218-19, 2N2221-22 2N2904 thru 2N2907	---	I_{CBO}	--- --- --- ---	.01 .02 10 20	μAdc
Collector Cutoff Current (V_{CE} = 30 Vdc, V_{BE} = 0.5 Vdc)	2N2904 thru 2N2907	---	I_{CEX}	---	50	nAdc
Base Cutoff Current (V_{CE} = 30 Vdc, V_{BE} = 0.5 Vdc)	2N2904 thru 2N2907	---	I_{BL}	---	50	nAdc
Collector-Emitter Saturation Voltage* (I_C = 150 mAdc, I_B = 15 mAdc) (I_C = 500 mAdc, I_B = 50 mAdc)	All Types All Types	12, 15	$V_{CE\,(sat)}$*	--- ---	0.4 1.6	Vdc
Base-Emitter Saturation Voltage* (I_C = 150 mAdc, I_B = 15 mAdc) (I_C = 500 mAdc, I_B = 50 mAdc)	All Types All Types	13, 16	$V_{BE\,(sat)}$*	--- ---	1.3 2.6	Vdc
DC Forward Current Transfer Ratio (I_C = 0.1 mAdc, V_{CE} = 10 Vdc)	2N2218, 2N2221, 2N2904, 2N2906 2N2219, 2N2222, 2N2905, 2N2907	10 11	h_{FE}	20 35	--- ---	---
(I_C = 1.0 mAdc, V_{CE} = 10 Vdc)	2N2218, 2N2221, 2N2904, 2N2906 2N2219, 2N2222, 2N2905, 2N2907			25 50	--- ---	
(I_C = 10 mAdc, V_{CE} = 10 Vdc)	2N2218, 2N2221, 2N2904, 2N2906 2N2219, 2N2222, 2N2905, 2N2907			35 75	--- ---	
(I_C = 150 mAdc, V_{CE} = 10 Vdc)*	2N2218, 2N2221, 2N2904, 2N2906 2N2219, 2N2222, 2N2905, 2N2907			40 100	120 300	
(I_C = 500 mAdc, V_{CE} = 10 Vdc)*	2N2218, 2N2221, 2N2904, 2N2906 2N2219, 2N2222, 2N2905, 2N2907			20 30	--- ---	

Dynamic Characteristic		Fig. No.	Symbol	Min	Typ	Max	Unit
Output Capacitance (V_{CB} = 10 Vdc, I_E = 0, f = 100 kc)	All Types	4	C_{ob}	---	---	8	pf
Input Capacitance (V_{BE} = 0.5 Vdc, I_C = 0, f = 100 kc) (V_{BE} = 2 Vdc, I_C = 0, f = 100 kc)	2N2218-19, 2N2221-22 2N2904 thru 2N2907	4	C_{ib}	--- ---	--- ---	30 30	pf
Current Gain - Bandwidth Product (I_C = 20 mAdc, V_{CE} = 20 Vdc, f = 100 mc) (I_C = 50 mAdc, V_{CE} = 20 Vdc, f = 100 mc)	2N2218-19, 2N2221-22 2N2904 thru 2N2907	8	f_T	250 200	--- ---	--- ---	mc
Delay Time	2N2904 thru 2N2907	1	t_d	---	6	10	nsec
Rise Time	2N2904 thru 2N2907	1	t_r	---	20	40	nsec
Turn-On Time	2N2218-19, 2N2221-22 2N2904 thru 2N2907	1	t_{on}	--- ---	26 26	--- 45	nsec
Storage Time	2N2904 thru 2N2907	2	t_s	---	50	80	nsec
Fall Time	2N2904 thru 2N2907	2	t_f	---	20	30	nsec
Turn-Off Time	2N2218-19, 2N2221-22 2N2904 thru 2N2907	2	t_{off}	--- ---	70 70	--- 100	nsec
Total Switching Time	All Types	3	t_{total}	---	12	---	nsec

*Pulse Test, Pulse Width $\leq$ 300 μsec, Duty Cycle $\leq$ 2%

PNP SWITCHING-TIME TEST CIRCUITS

For NPN Switching Tests, reverse diodes, polarities, and input pulses.

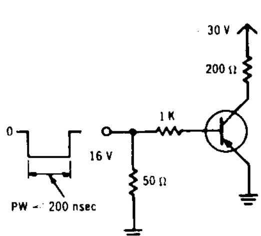


FIGURE 1 — SATURATED TURN-ON SWITCHING-TIME TEST CIRCUIT

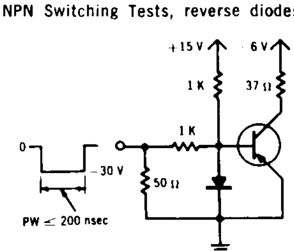


FIGURE 2 — SATURATED TURN-OFF SWITCHING-TIME TEST CIRCUIT

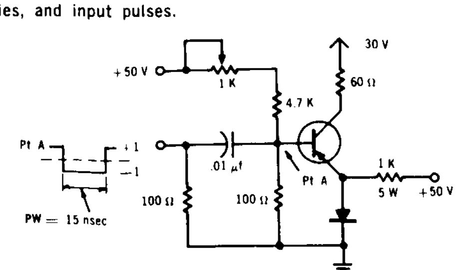


FIGURE 3 — NON-SATURATED SWITCHING-TIME TEST CIRCUIT

DYNAMIC CHARACTERISTICS, $T_A = 25°C$

FIGURE 4 — CAPACITANCE VARIATIONS versus VOLTAGE

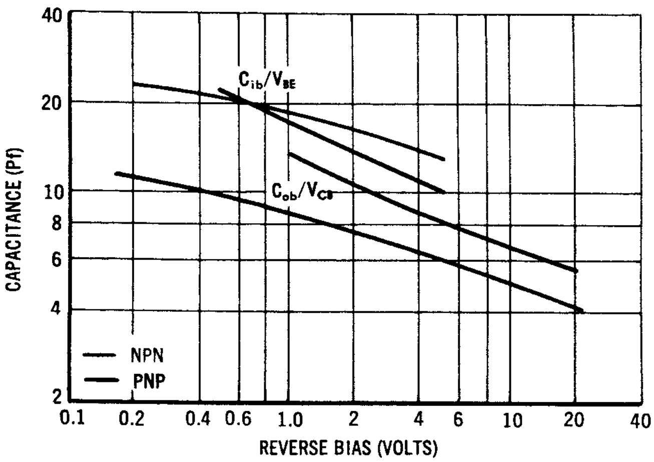


FIGURE 5 — ACTIVE REGION TIME CONSTANT versus COLLECTOR CURRENT

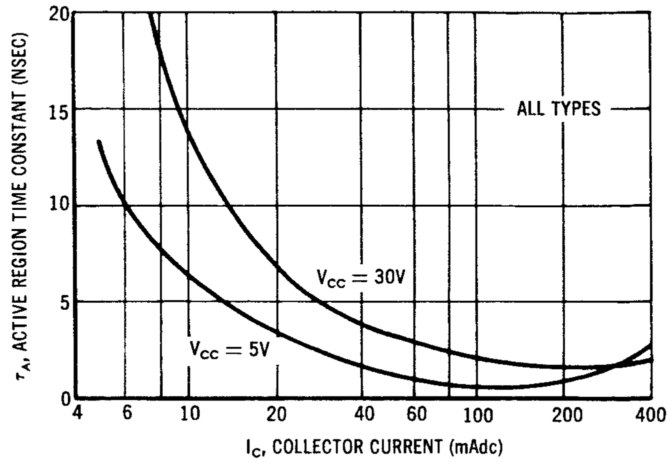


FIGURE 6 — TOTAL CONTROL CHARGE versus BASE CURRENT

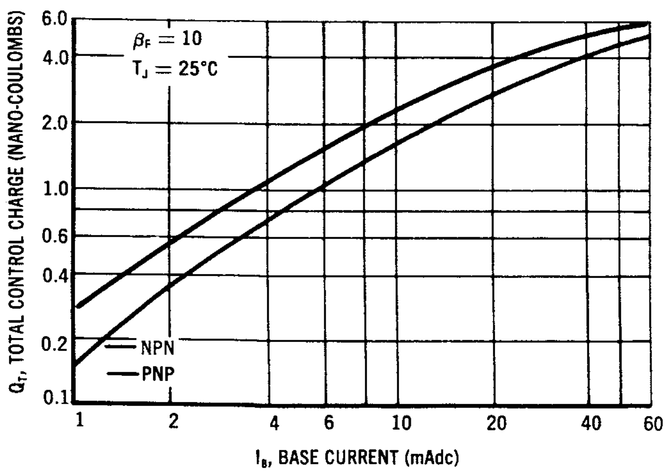
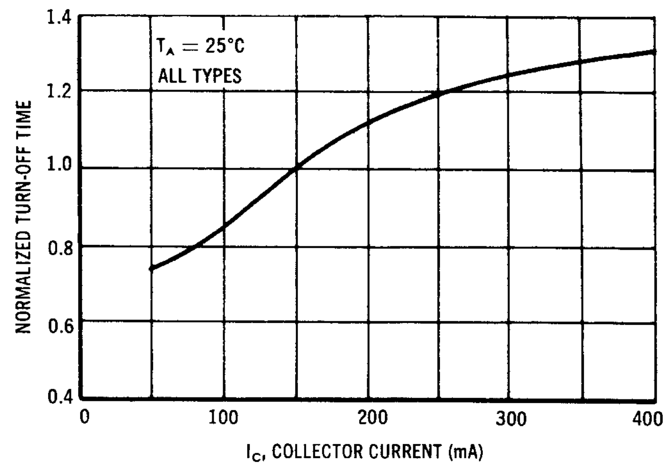
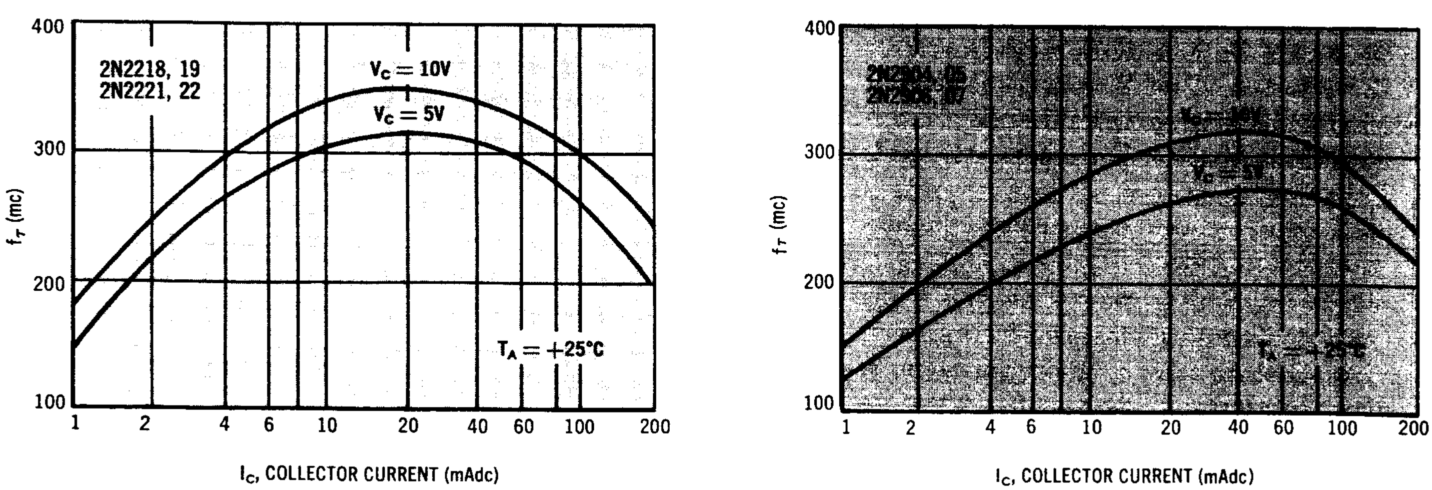


FIGURE 7 — NORMALIZED TURN-OFF TIME versus COLLECTOR CURRENT



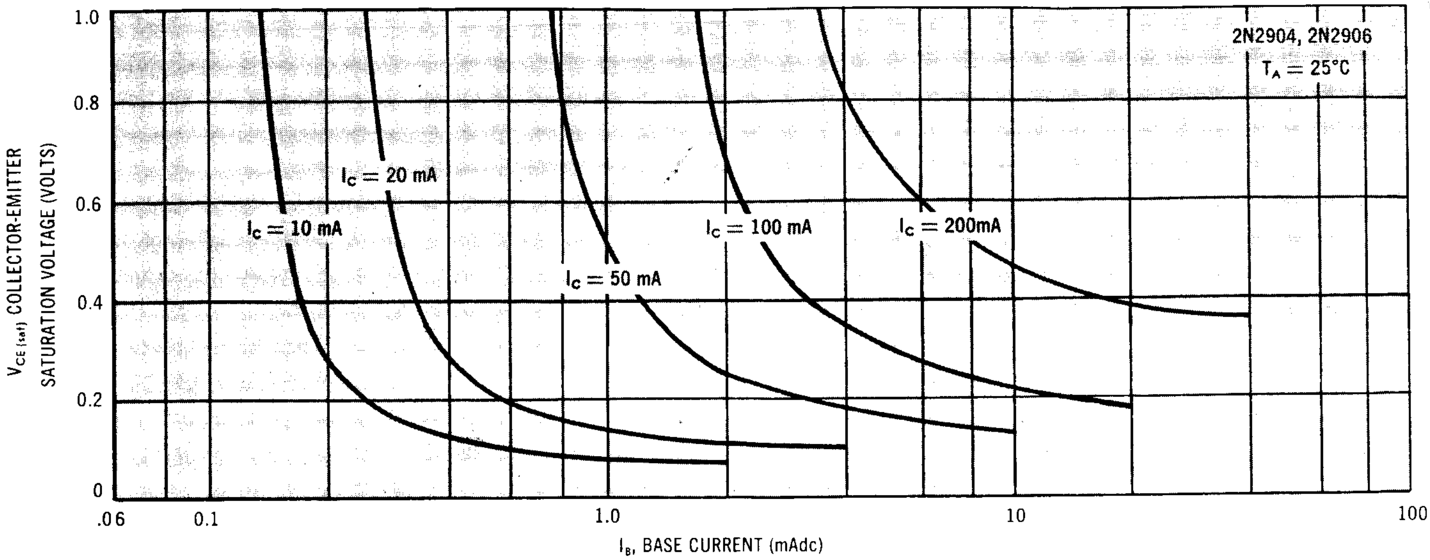
NPN **PNP**

FIGURE 8 — CURRENT GAIN-BANDWIDTH PRODUCT versus COLLECTOR CURRENT



PNP

FIGURE 15 — COLLECTOR SATURATION VOLTAGE versus BASE CURRENT



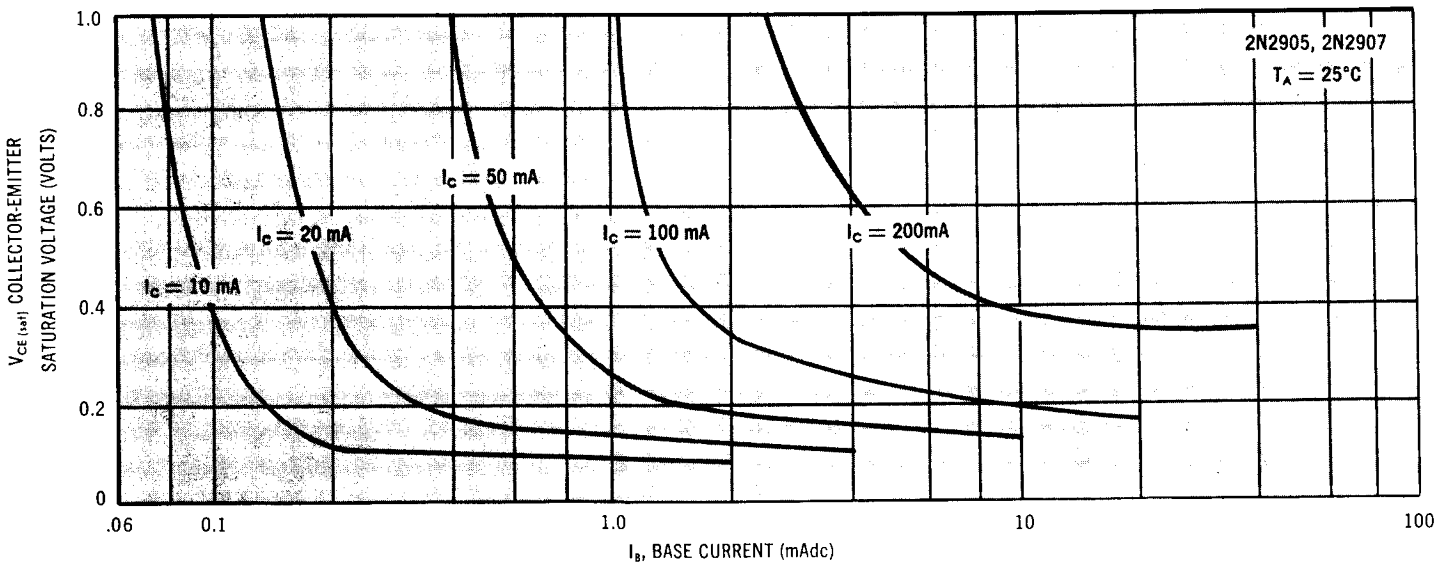


FIGURE 16 — BASE SATURATION VOLTAGE versus BASE CURRENT

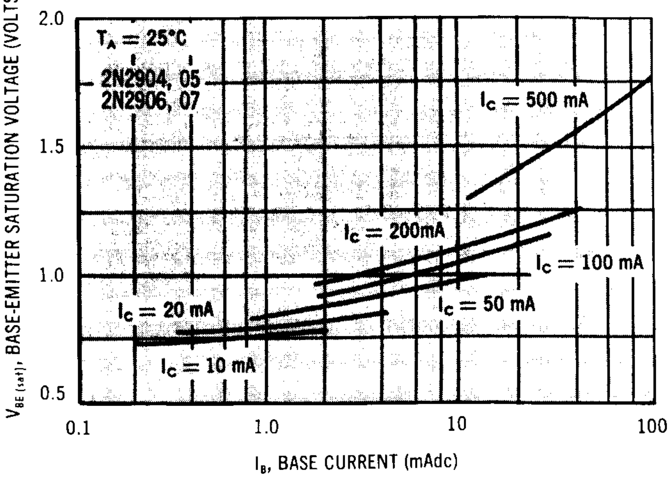
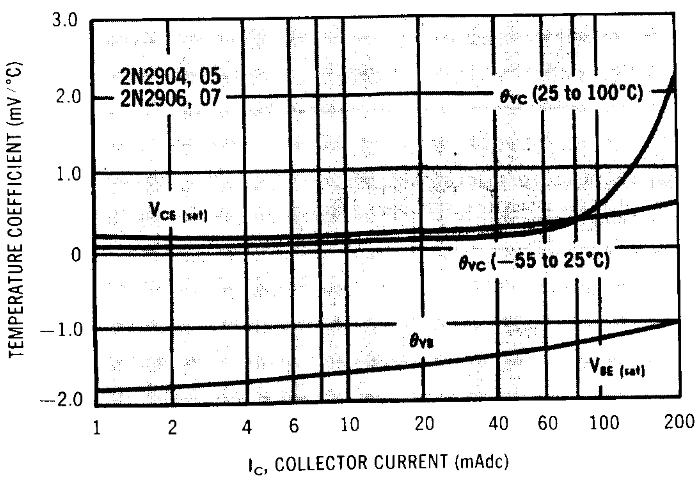


FIGURE 17 — TEMPERATURE COEFFICIENTS

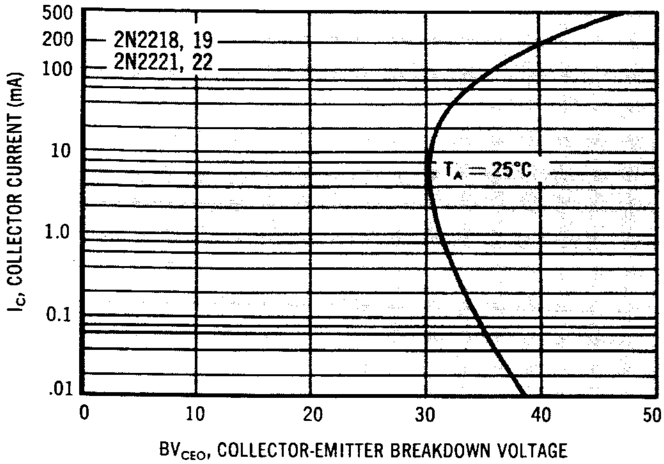


STATIC CHARACTERISTICS

NPN

PNP

FIGURE 9 — COLLECTOR CURRENT versus MINIMUM COLLECTOR-EMITTER BREAKDOWN VOLTAGE



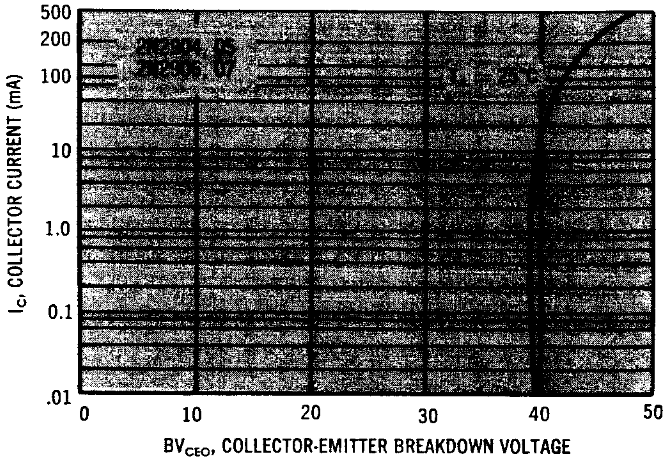
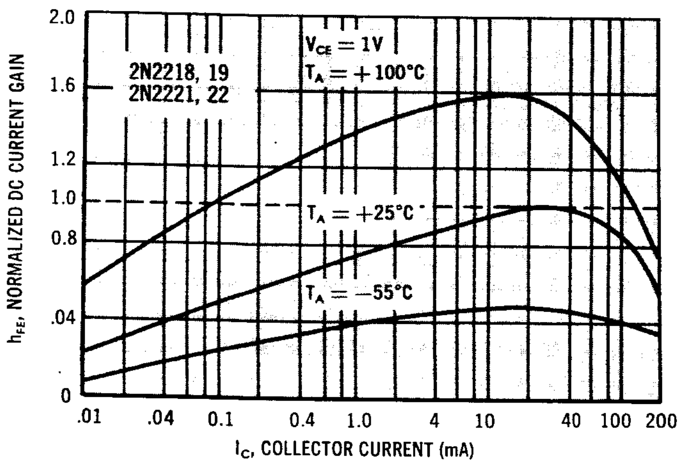


FIGURE 10 — LOW CURRENT GAIN



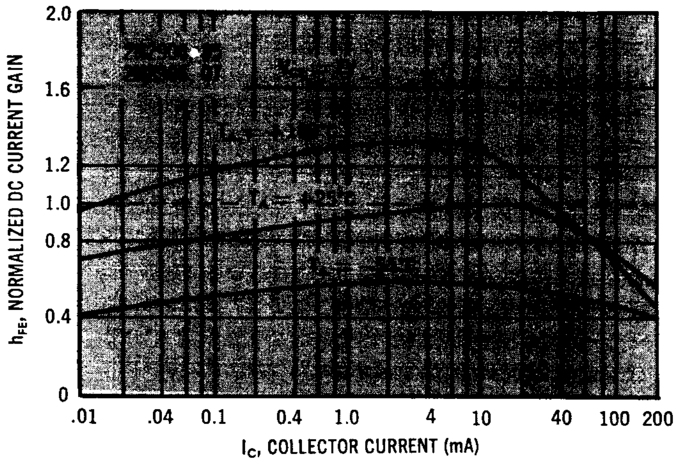
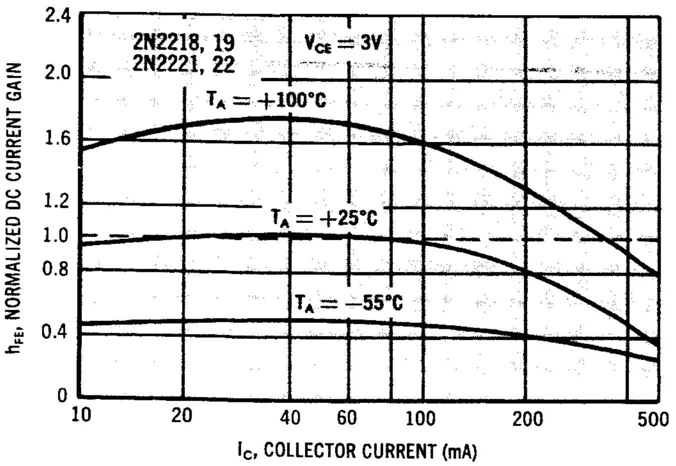
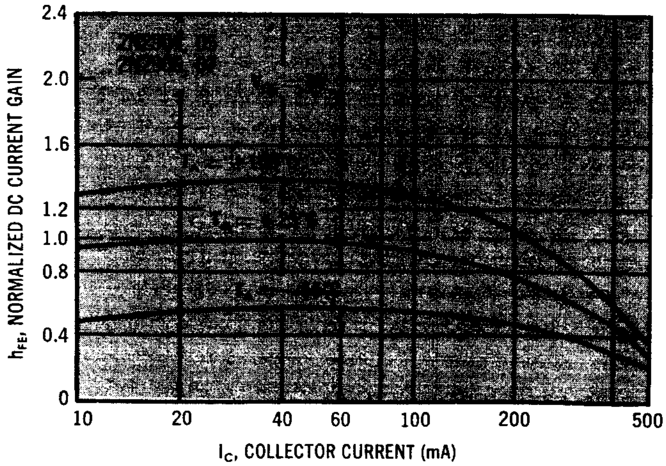


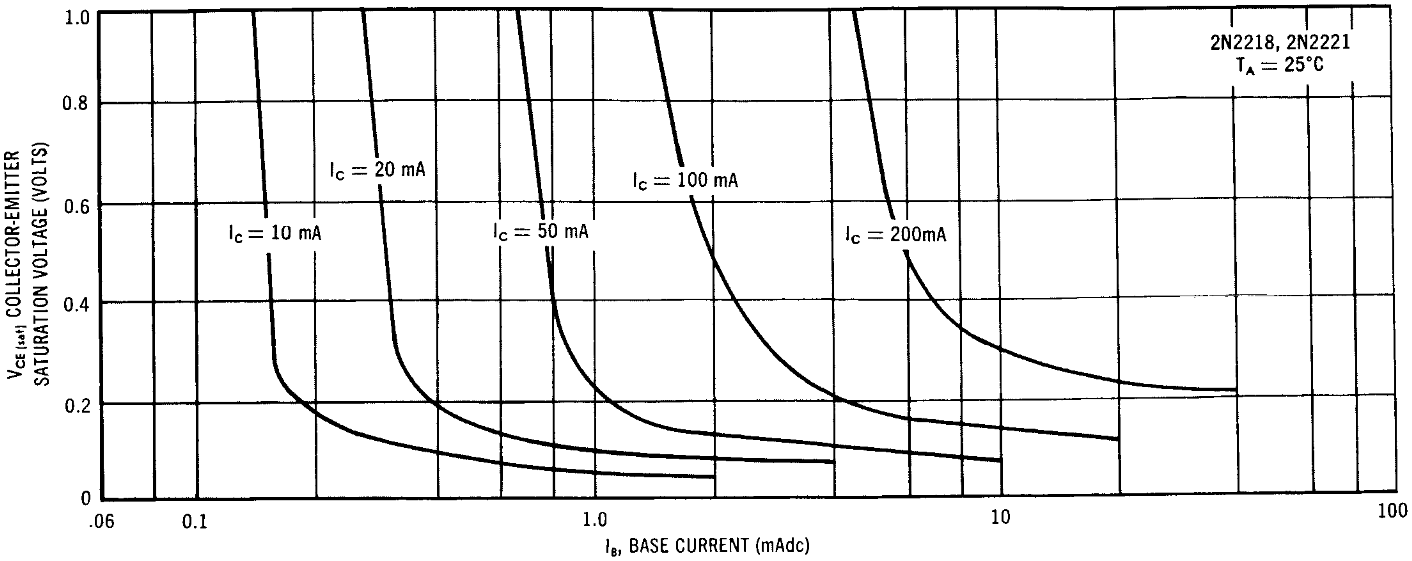
FIGURE 11 — HIGH CURRENT GAIN





NPN

FIGURE 12 — COLLECTOR SATURATION VOLTAGE versus BASE CURRENT



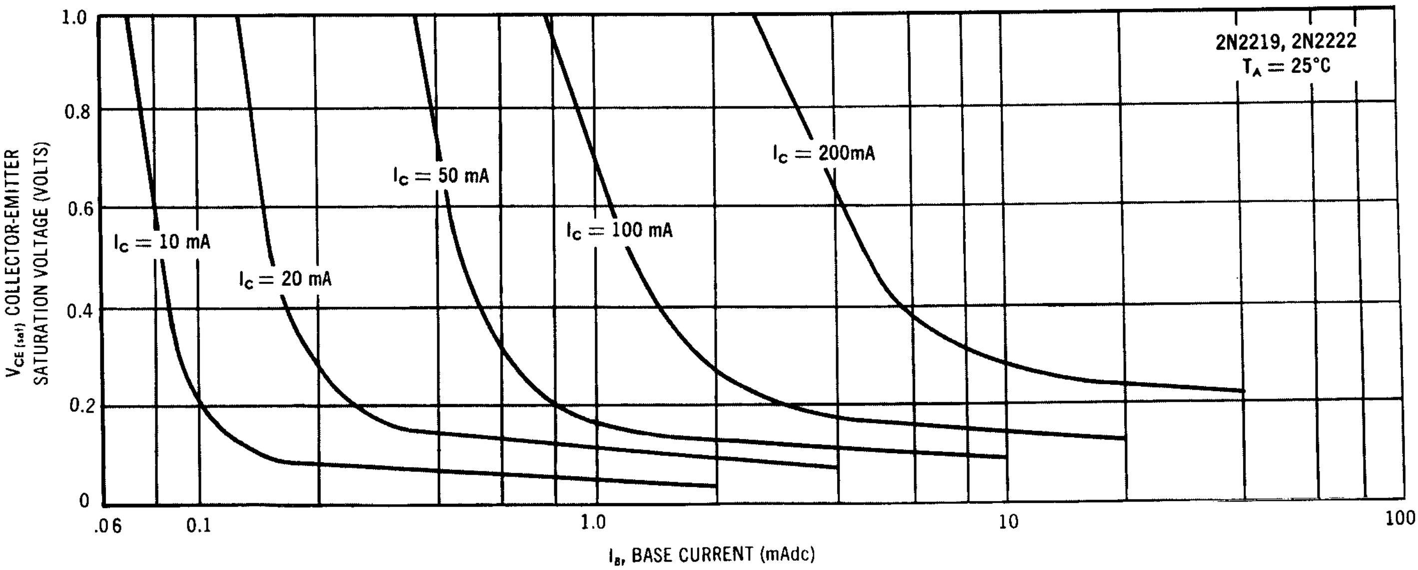


FIGURE 13 — BASE SATURATION VOLTAGE versus BASE CURRENT

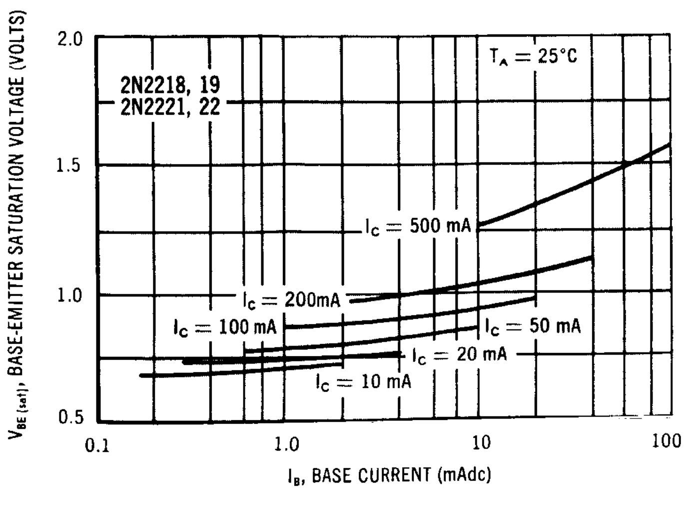


FIGURE 14 — TEMPERATURE COEFFICIENTS