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E-2218

LEAD FAILURE STUDY FOR THE
MOTOROLA 1-MIL WEDGE-BONDED
1006323 TRANSISTOR

by
William Day
Jayne Partridge

DECEMBER 1967

MIT

CAMBRIDGE 39, MASSACHUSETTS

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ACKNOWLEDGMENT

This report was prepared under DSR Project 55-23850, sponsored by the Manned Spacecraft Center of the National Aeronautics and Space Administration through Contract NAS 9-4065 with the Instrumentation Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

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WEDGE-BONDED 1006323 TRANSISTOR

ABSTRACT

This report presents the results of a thermal analysis of the failure modes for the 1-mil diameter aluminum lead wires of the SCD 1006323 wedge-bonded transistor.

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LEAD FAILURE STUDY FOR THE MOTOROLA 1-MIL
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Due to a large increase in failures during and after screen and burn-in for the Apollo Block II aluminum wedge-bonded transistors (1006323) as compared to the previous Block I gold-ball bonded transistors, studies were undertaken to find the cause of this failure increase. Since the major structural difference in the units was in the lead material, the effort centered on their reliability.

Visual observation of the aluminum transistor leads during switching mode operation revealed that considerable motion of the emitter lead was occurring as the current level through the lead changed. This movement could possibly cause fatigue and ultimately lead failure after repeated cycling. It was also noted that the motion consisted of two distinct phases, a quick jump occurring on the order of a few tenths of a second, followed by a slow shift lasting on the order of tens of seconds.

A thermal analysis of the lead was conducted to determine the cause of this phenomena and to establish to what extent this phenomena influences the reliability of the transistor.

This analysis was carried out in three steps. First the chip and the 1-mil aluminum leads were exposed by removing the cans from ten samples. Chip temperature and lead temperature were then measured using the Barnes Engineering Co. infrared radiometers RM-2B and RM-2A. This was performed for both switching and DC operating conditions at various power levels and lead currents. Secondly, as a backup method, the lead resistance was simultaneously monitored using a Boonton sensitive dc voltmeter and microprobe techniques. Since the lead temperature and its resistance are directly related, this method was used to measure the high speed thermal response of the lead directly. The last step consisted of the measurement of the response of the lead itself without the sinking effects of the chip. To accomplish this, 1-mil diameter aluminum lead wires 0.15" long were ultrasonically bonded between the posts of TO-5 headers. These were then subjected to various current levels and the temperature and resistance were measured as before, giving the response of the isolated lead. The results of these investigations are given below.

Emitter Lead Power Dissipation

Results of the emitter lead resistance measurements showed that the lead resistance remained relatively constant in the current range of 200 ma to 500 ma (Figs. 1, 2). Above 500 ma, the resistance increased very rapidly indicating a drastic temperature increase and correspondingly higher power dissipation in the lead itself. This condition generally leads to the failure of the unit, as the higher the lead temperature goes, the higher the lead resistance goes which increases lead power dissipation and in turn increases lead temperature. This point of "thermal runaway" was found to occur at a current of approximately 750 ma. This mode of failure of the lead generally leaves the chip intact and in good condition with the lead fused near its midpoint.

Visual observation of the lead undergoing current switching indicated that at the 550 ma region, lead motion began to increase significantly. It is interesting to note that at 550 ma, the lead is dissipating approximately 10% of the total power dissipated by the entire unit.

The emitter lead power dissipation was mainly dependent on lead current with only slight dependence on chip power dissipation (Fig. 3). As can be expected, lead power showed a definite correlation to lead temperature and resistance (Fig. 4).

Thermal Response of Lead

To determine if the Joulian heating in the lead was responsible for the flexing, thermal plots of the time response and temperature distribution of the lead were made. Figure 4 gives the emitter lead temperature as a function of emitter lead current. The thermal time constants of the chip, the lead connected to the chip, and the isolated lead were measured. (Figure 5 gives a typical thermal response of a lead connected to the chip as it occurs in the unit.)

τ_r = thermal rise time, τ_f = thermal fall time.

1. Emitter lead (connected to chip).

$$\tau_r = 28.5 \text{ sec.}$$

$$\tau_f = 11.5 \text{ sec.}$$

2. Chip (at center).

$$\tau_r = 27.5 \text{ sec.}$$

$$\tau_f = 17.5 \text{ sec.}$$

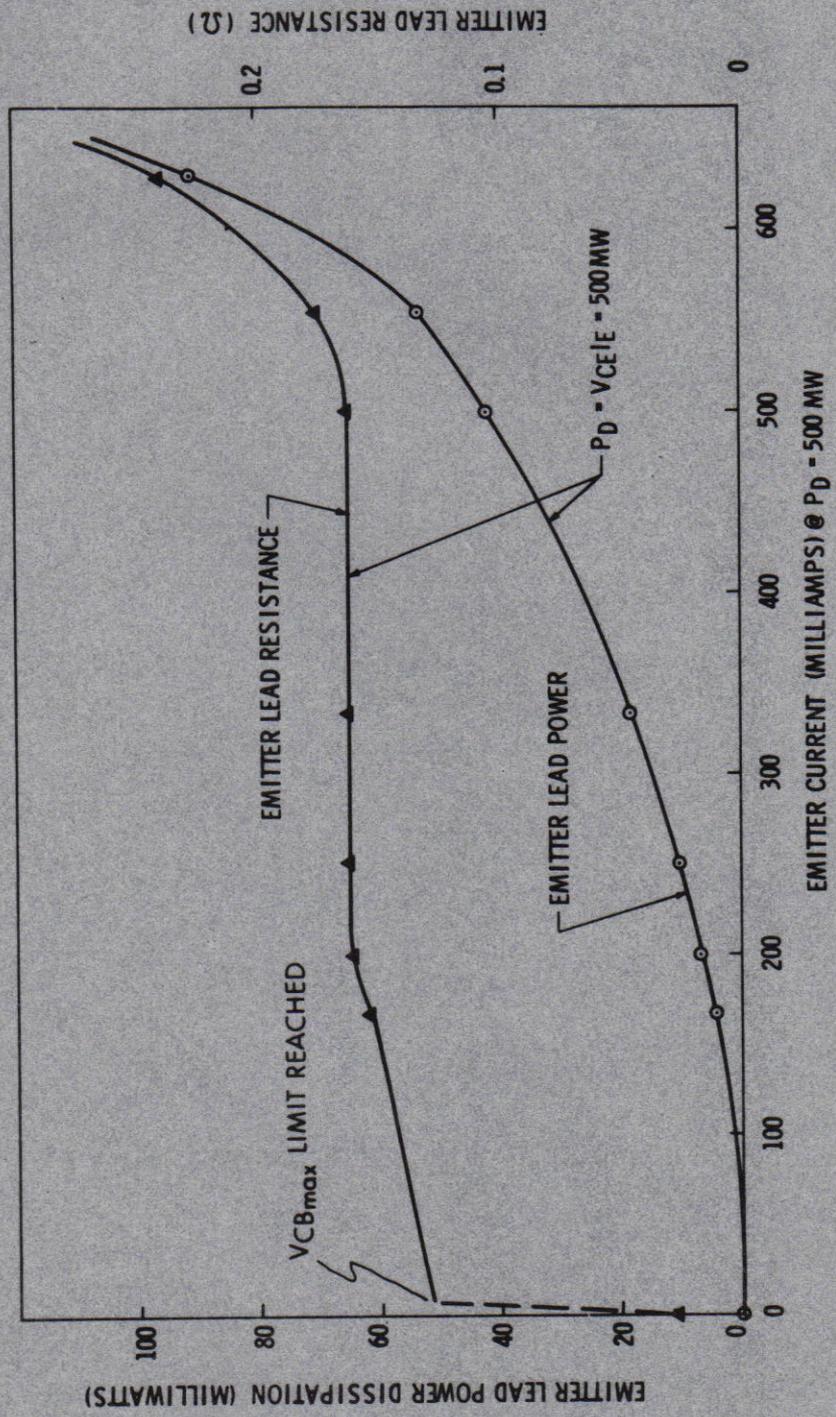


Fig. 1 Emitter Lead Res. and Emitter Lead Power Dissipation vs. Emitter Current at 500 mw Chip Power.

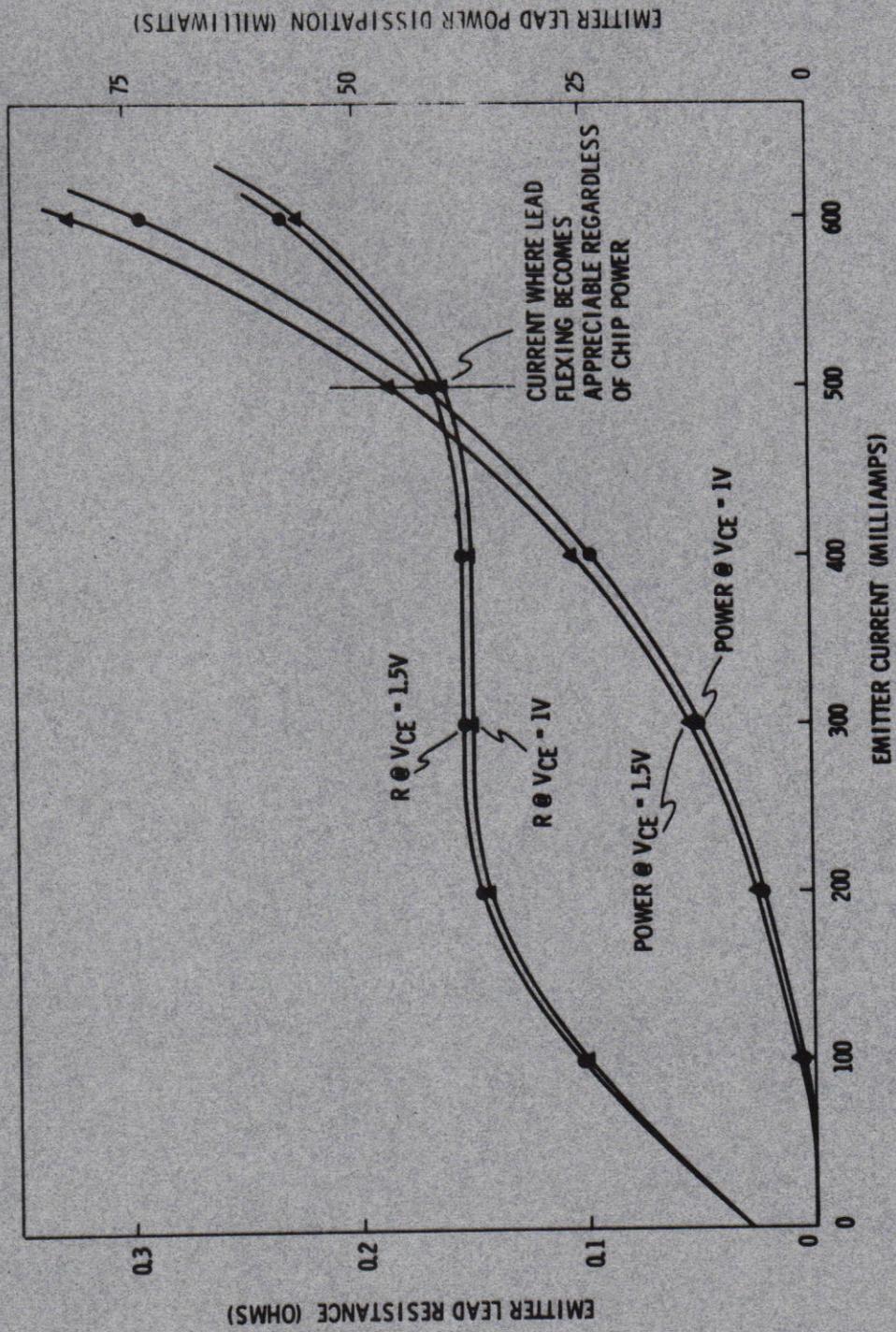


Fig. 2 Emitter Lead Power and Resistance vs. Emitter Current.

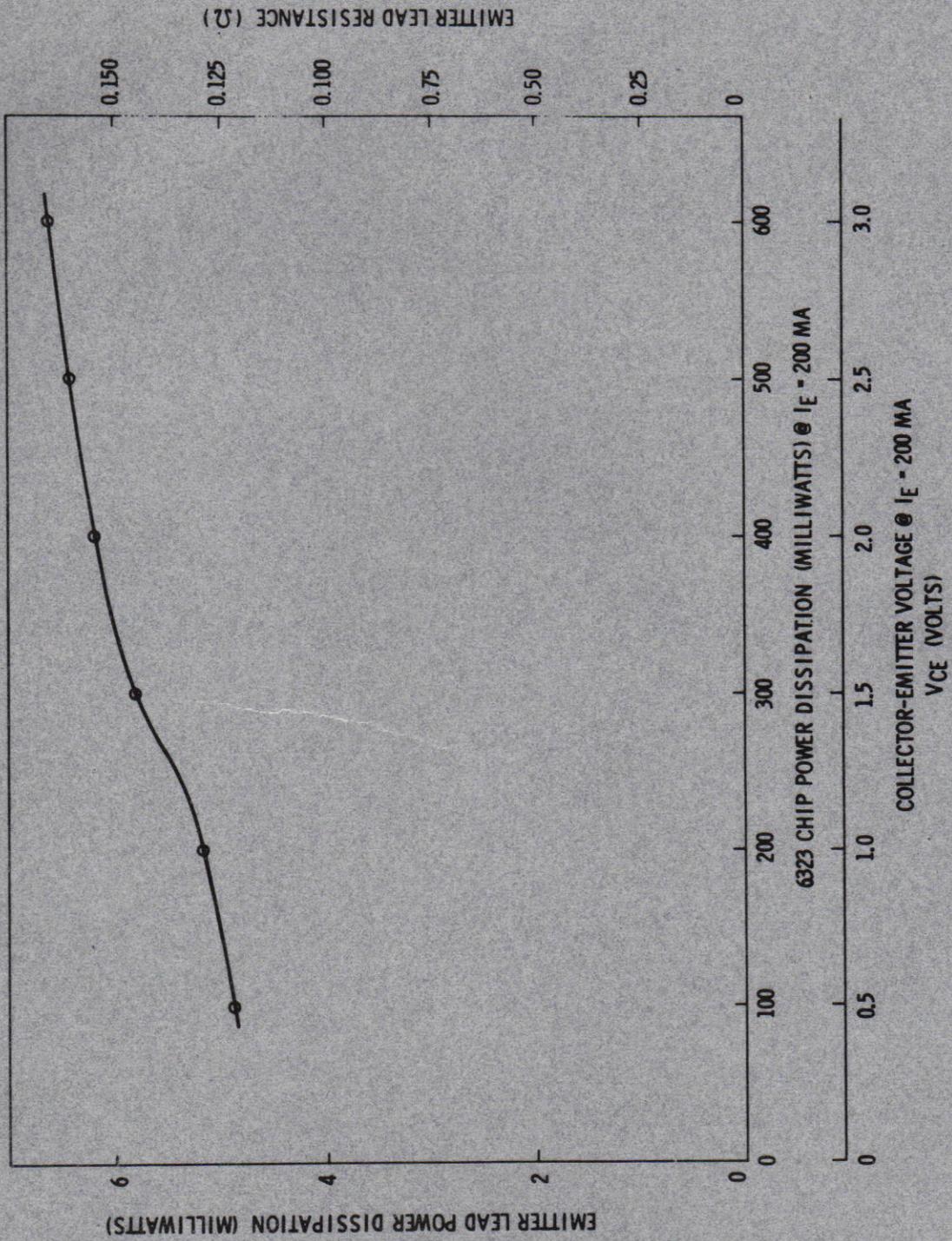


Fig. 3 Emitter Lead Power vs. Chip Power at Constant Emitter Current.

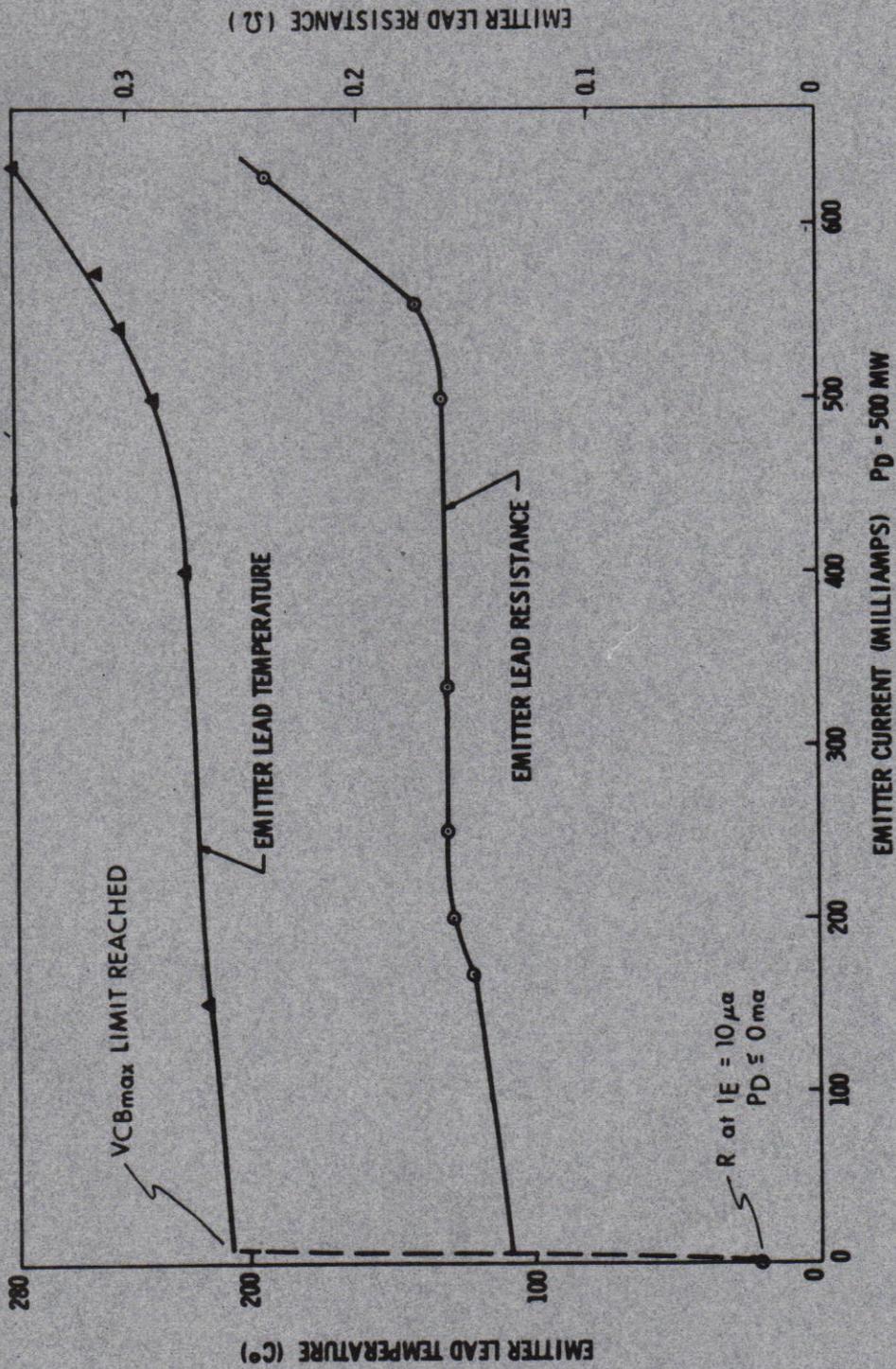


Fig. 4 Emitter Lead Temp. and Resistance vs. Emitter Current at 500 mW Chip Power.

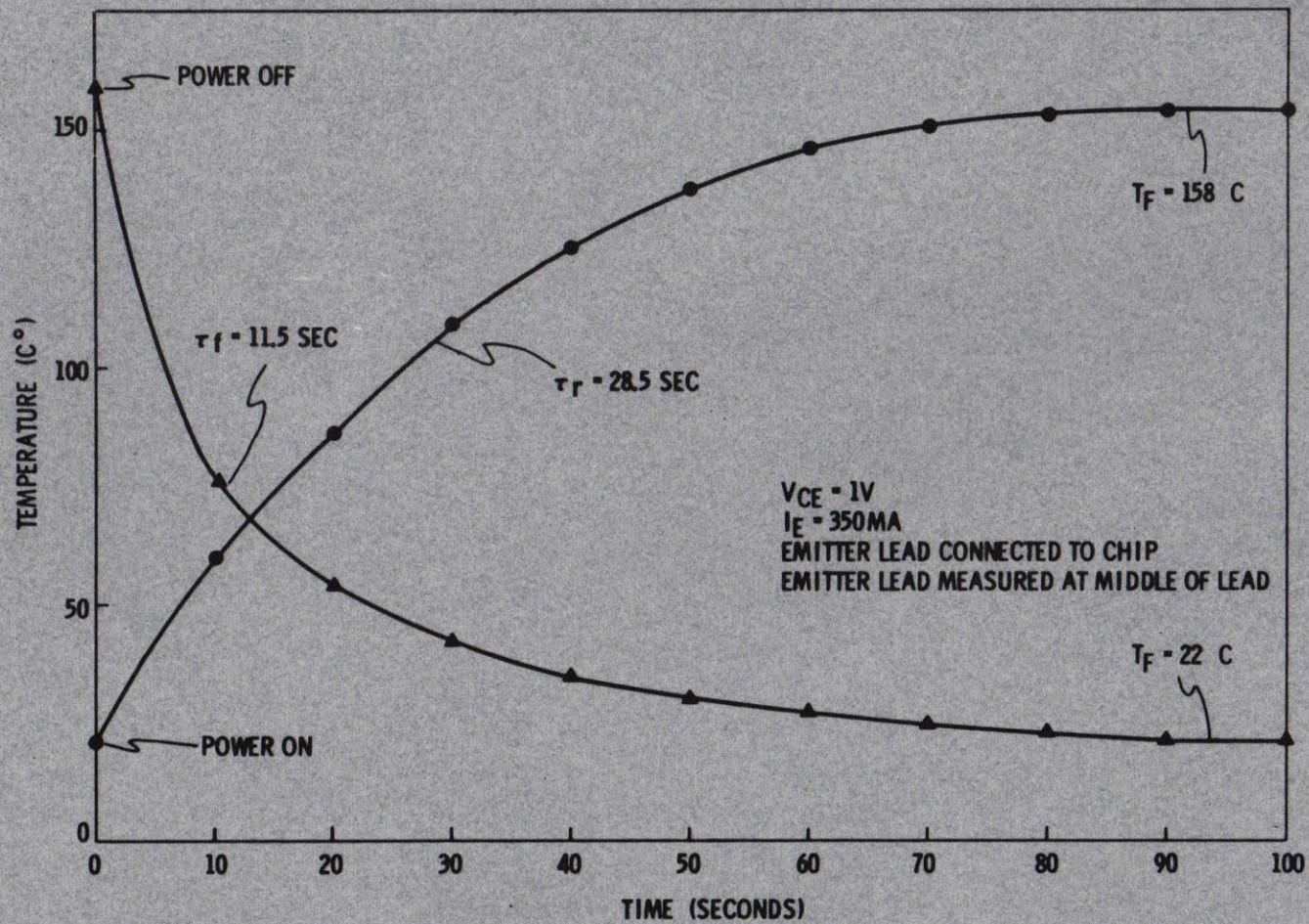


Fig. 5 Thermal Response of Emitter Lead.

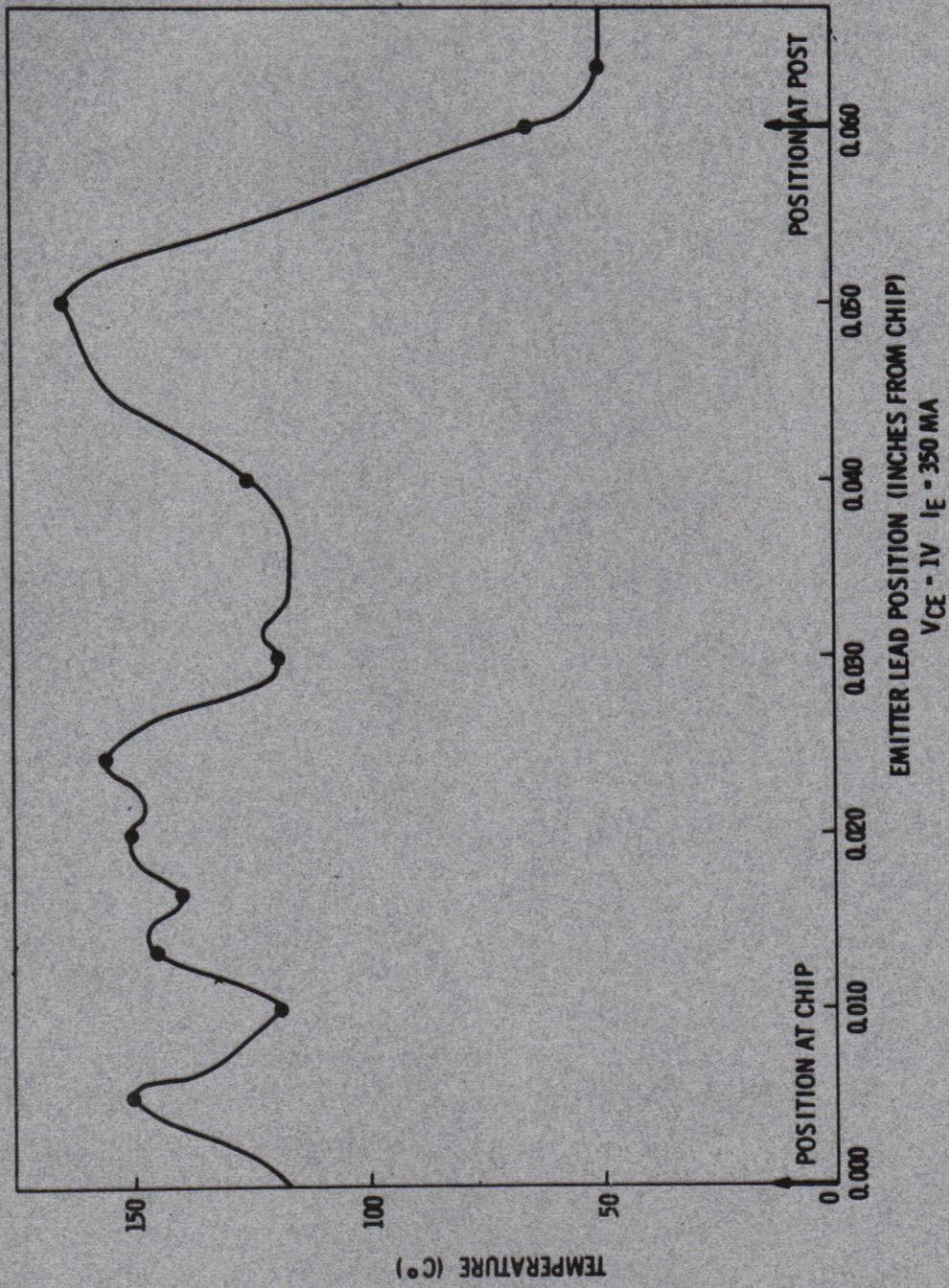


Fig. 6 Emitter Lead Temperature Distribution (at Thermal Equilibrium).

3. Chip (at corner).

$$\tau_r = 31.0 \text{ sec.}$$

$$\tau_f = 22.0 \text{ sec.}$$

4. Emitter lead (isolated; connected between two kovar posts).

$$\tau_r = 0.38 \text{ sec.}$$

$$\tau_f = 0.40 \text{ sec.}$$

This data indicated that the chip has considerable thermal sinking action on the lead, which would keep the lead temperature fairly close to the chip temperature by heat conduction along the lead. This is supported by the large time constant of the lead when connected to the chip, and the much shorter constant when isolated. Additional evidence is shown by the thermal distribution plot of the lead (Fig. 6), which indicates that most of the lead material is at or near the chip temperature at thermal equilibrium.

Observations

This evidence would explain the existence of the "short jump and slow shift" motion of the lead. On cooling the lead would follow the decay of the chip, but somewhat lower because of better cooling, less thermal mass and thermal conduction gradients. As the power was applied, the lead would quickly respond by heating ($\tau_r = 0.4$ sec) until the thermal sinking of the chip took predominance, after which the lead would follow the chip heating but at a slightly higher temperature due to its internal heating and conduction to the massive chip. This would cause the "quick jump" due to the fast thermal expansion of the lead as it went from a temperature somewhat below the chip temperature for cooling to somewhat above the chip temperature for heating.¹ (This quick motion is observed to occur in approximately the time constant of the isolated lead $\tau = 0.4$ sec). From then on the lead temperature would follow the chip temperature giving rise to the slow shift also caused by thermal expansion (or contraction) of the lead. Thermal motion of the chip itself was undetectable at X200, while motion of the lead was easily discernable, ruling out chip motion as the predominant factor in the phenomenon. This lead motion became noticeably more apparent at current levels above 550 ma.

¹Calculations using the thermal coefficient of expansion for aluminum ($25 \times 10^{-6}/C^\circ$) and the lead length of 0.150" indicate that a temperature change of less than $1^\circ C$ will cause a motion of the center of the lead of 0.0005" (half a lead dia.). This small temperature difference is well within the error of the radiometer readings, thus explaining the lack of measured temperature change accompanying the "short jump" of the lead.

Conclusions

1. Lead current should be limited to 500 ma at most to avoid excessive lead motion.
2. This lead motion seems to be caused by thermal expansion of the lead following the chip temperature generally with small transients occurring at transitions from cooling to heating or vice versa.

To test the reliability of these transistors, a group of one hundred were placed on life test under the following conditions:

Group #1	$V_{CE} = 30 \text{ v}; I_{CE} = 315 \text{ ma}$
(50 transistors)	On for 20 msec, off for 980 msec
	Duty cycle - 2.0%.

Group #2	$V_{CE} = 15 \text{ v}; I_{CE} = 260 \text{ ma}$
(50 transistors)	1 μsec on, 5 μsec off for 20 msec
	of 980 msec
	Duty cycle - 0.33%

Results of the life test indicate no failures after an excess of 10 million cycles by each group. This test supports the evidence that the lead flexing failure mode is negligible below 500 ma emitter current.

Since the cycle time of the 6323 transistor burn-in at Raytheon is in the order of minutes, the burn-in failures may be attributed to lead fatigue caused by lead flexing due to chip heating. As many as 3% failures due to lead breakage of the 1-mil Al bent lead would occur after 5000 cycles. The life test data above shows that no failures occur after 10,000,000 cycles if the cycle time is tens of milliseconds. It can therefore be concluded that module and field failures are not caused by a fatigue mechanism. This is verified by the fact that module and field failures show no relation to the worst case current and power applications. The module and field failures must then be caused by mechanical or thermal shock stresses, or intermittent contact caused by a broken lead making touch contact.

E-2218

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