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STORAGE RELIABILITY OF CHIP AND BOND WIRE ELECTRONIC DEVICES

VOLUME I - DATA ANALYSIS

DECEMBER 8, 1975

ARMY SYSTEMS DIVISION
BOEING AEROSPACE COMPANY
HUNTSVILLE OPERATIONS

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VOLUME I - DATA ANALYSIS

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PREFACE

This program was conducted by Boeing Aerospace Company's Army Systems Division in Huntsville, Alabama under Contract DAAH01-75-C-0835, "Storage Reliability Retest Program for Minuteman Electronic Components." The study was directed by Rex Provence, U.S. Army Missile Command (MICOM). Larry McTigue was Boeing Program Manager. Testing and failure analysis was performed by the Boeing Minuteman Reliability Engineering Organization, with Robert Frank as Principal Investigator.

This study is part of MICOM's Storage Reliability Technology program. Materiel in the Army inventory - particularly missile systems - must withstand long periods of storage and "launch ready" non-activated dormancy. Within the Department of Defense, MICOM has lead responsibility to develop the Data Bank and supporting methodology required to design, manufacture and package hardware for this non-operating environment. The results contained herein will be incorporated into the Data Bank and used to predict storage reliability characteristics for electronic parts of chip and bond wire design.

We wish to acknowledge the contributions of the MICOM Technical Manager, Rex Provence, Product Assurance Directorate, whose direction and technical comments made the results of this study a more valuable part of the overall Storage Reliability Program.

Questions on the contents of this report should be directed to Larry McTigue, Boeing Aerospace Company, P. O. Box 1470, Huntsville, Alabama 35807, phone (205) 837-5520.

ABSTRACT

Storage reliability and parameter drift rates were measured on 10,027 Minuteman chip and bond wire Resistor-Transistor Logic (RTL) devices, which have been in storage since mid-1967 (eight years). Three parts failed as a result of the eight years of storage. Analysis of the failed parts showed all three were caused by oxide defects which allowed the deposited aluminum metalization to contact the active silicon of the die and short to ground. *The 90% confidence level values for Failure Rate and Mean Time Between Failure are 0.0095x10^{-9} failures/part-hr and 105x10^{6} part-hrs/failure, respectively.* [illegible] 105 million

After eight years of storage, none of the parts experienced a single bond wire failure, no external leads were corroded or broken and there were no package problems. This is evidence of the high storage reliability that can be achieved with proper design, manufacturing and test procedures.

Parameter drift measurements showed the resistor elements virtually unchanged after 8 years of storage. *However, the transistor elements showed a significant degradation in gain characteristics.* The gain changes are attributed to migration of contaminants (which are always present in minute amounts), and/or to changes in the gold doping process used in the manufacture of the parts. The average rate of drift ranged from 1-2% per year, depending on the logic function circuit involved. Substantially higher rates of drift - up to 7% per year - occurred in parts whose 1967 measured performance fell more than one standard deviation (-1σ) below the mean. About 2% of the parts measured had drifted close enough to specification limits to be classed as "incipient failures" (Parts that are likely to drift out of specified performance levels in 10 years of storage or less). With one exception, all of these "incipient failures" were -1σ parts or worse when tested in 1967. *The strong correlation between original measured performance and drift rate suggests that storage life can be enhanced significantly by rejecting parts that fall below the -1σ level during acceptance testing.* Rejecting the 16% of the parts that fall outside the -1σ value would reduce the number of parameter drift failures that could be expected during 10 years of storage from 2% of the population to less than 0.1%.

Study results are presented in two volumes. Volume I, Data Analysis (this volume) presents the findings, backed by summary plots and tables of reduced test data. Volume II, Test Results, tabulates all parameter measurements made on each part tested.

STORAGE RELIABILITY OF CHIP AND BOND WIRE ELECTRONIC DEVICES

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INTRODUCTION AND SUMMARY

1.0 INTRODUCTION

In July 1967, over eight years ago, 10,027 Motorola RTL electronic parts of chip and bond wire design were placed in room temperature storage. Prior to storage, each part was burned in (168 hours @ 125°C), then tested to record the performance of each parameter. Starting in July of 1975, the parts were removed from storage and the original test program repeated to obtain Storage Reliability data for chip and bond wire devices. As shown in Figure 1-1, the retest program consisted of the following two elements:

1) Measurement of storage failure rates, followed by analysis of the failures to identify failure modes and mechanisms and to establish product improvement guidelines.

2) Measurement of parameter drift characteristics and analysis of results to establish incipient failures, drift rates, and projected shelf life.

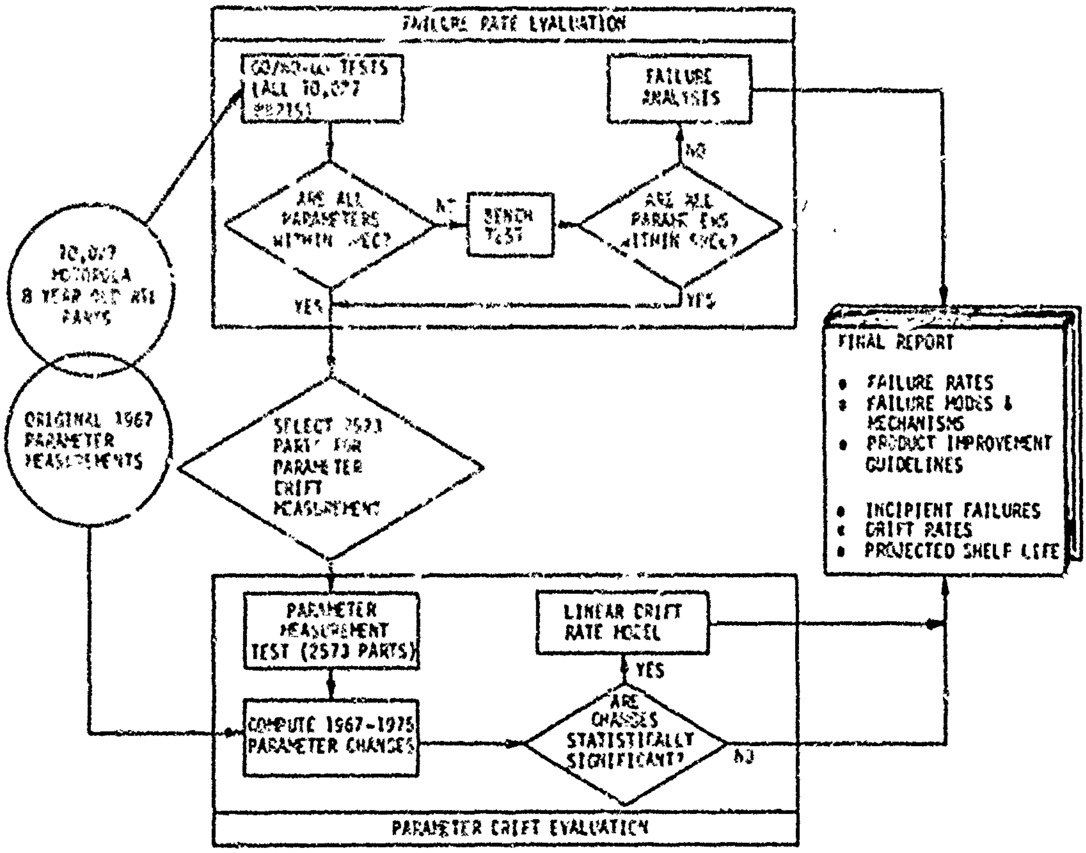


FIGURE 1-1. PROGRAM OVERVIEW

1.0 INTRODUCTION (CONTINUED)

All 10,027 parts were subjected to Go/No-Go testing to detect failed parts (parts showing one or more parameters outside of specification limits). These parts were then individually bench tested. Confirmed failed parts were analyzed to establish the failure modes and mechanisms.

A randomly selected sample of 2573 parts passing Go/No-Go testing were run through the Parameter Drift test program. Selected currents and voltages representing resistor characteristics, transistor gains and leakage rates were measured and recorded. Computer analysis was performed to compare the 1975 test values with those measured in 1967. For those parameters showing statistically significant performance changes, a linear drift rate model was fit to the test data and used to predict remaining storage life.

1.1 SUMMARY

While all parts were of similar chip and bond wire design, devices having seven different logic functions were included in the inventory of parts tested (Table 1-I).

TABLE 1-I. INVENTORY OF PARTS BY LOGIC FUNCTION

LOGIC FUNCTION	MOTOROLA PART NO.	NO. OF PARTS FOR FAILURE RATE EVALUATION	NO. OF PARTS FOR PARAMETER DRIFT EVALUATION
Twin Buffer	SC 2207	1002	250
Adder	SC 2208	1002	250
Double Gate	SC 2210	2382	500
4-Input Gate	SC 2211	1250	348
Half-Adder	SC 2212	450	250
Register	SC 2213	2992	625
Expander	SC 2221	949	350
		10027	2573

A total of three parts failed as a result of the eight years of storage. Analysis of the failed parts showed all three were due to oxide defects which allowed the deposited aluminum metalization to contact the active silicon of the die and short to ground. Table 1-II summarizes the failures and the resulting failure rate statistics.

1.1 SUMMARY (Continued)

TABLE 1-II. FAILURE ANALYSIS SUMMARY

PART LOGIC FUNCTION	PART SERIAL NUMBER	FAILURE MODE/MECHANISM
DOUBLE GATE	1493	SHORT CAUSED BY OXIDE DEFECT UNDER AL STRIPE ON DIE CONNECTING TO PIN 1
EXPANDER	228	SHORT CAUSED BY OXIDE DEFECT UNDER BOND PAD 3
	561	SHORT CAUSED BY OXIDE DEFECT UNDER BOND PAD 6

TOTAL FAILURES = 3

TOTAL PART-HOURS OF STORAGE = 703×10^6

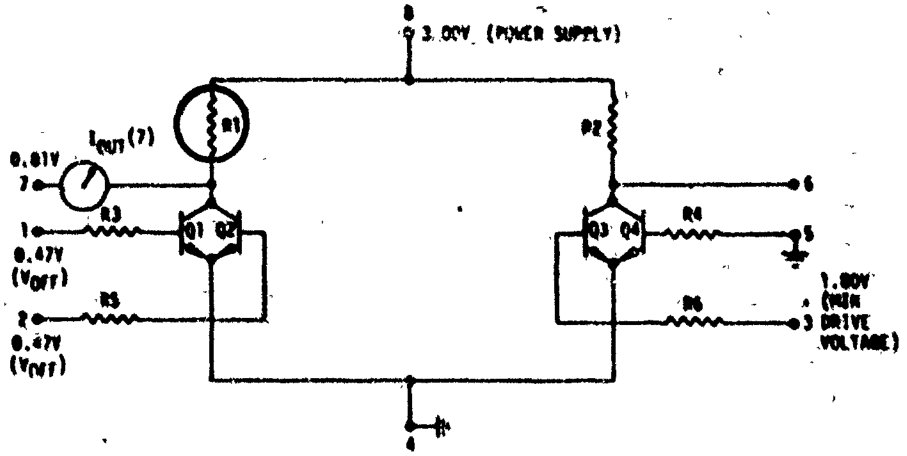
FAILURE RATE (FAILURES/PART-HR) = 0.0059×10^{-6} (60% CONFIDENCE LEVEL); 0.0095×10^{-6} (90% CONFIDENCE LEVEL)

MEAN TIME BETWEEN FAILURES (MTBF) (PART-HR/FAILURE) = 169×10^6 (60% CONFIDENCE LEVEL); 105×10^6 (90% CONFIDENCE LEVEL)

Results from the Parameter Drift Evaluation are typified by Figures 1-2 and 1-3 which compare 1967 and 1975 test results for parameters representing resistor and transistor performance, respectively. The 1975 measurements taken on the resistor elements are virtually unchanged from the 1967 values. Note that the 1967 and 1975 histograms (Figure 1-2b) are almost identical in shape and only differ by a 4 microamp bias. This bias is attributed to a slight difference in test set-up and is not an indication of parameter drift. This conclusion is confirmed by Figure 1-2c, which shows the 1967-1975 change in the I_{OUT} parameter. The near-normal distribution of this change is typical of scatter due to normal measurement error. It shows none of the skewness exhibited by true parameter drift.

The transistor elements did show a measurable loss of performance during the eight years of storage. Figure 1-3 is a typical comparison of changes in transistor gain. While the change in mean value is small (6 mv), the pronounced skewness of Figure 1-3c shows the changes are due to parameter drift rather than measurement error. There is significant performance loss in parts in the right hand tail of the distribution (parts whose original performance was more than one standard deviation below the 1967 mean). Degradation in the parts having the greatest rate of drift (parts occupying the shaded -2σ tail in Figure 1-3d) is shown by the heavy arrows in Figure 1-3d. Note that all these parts were below average performers in 1967.

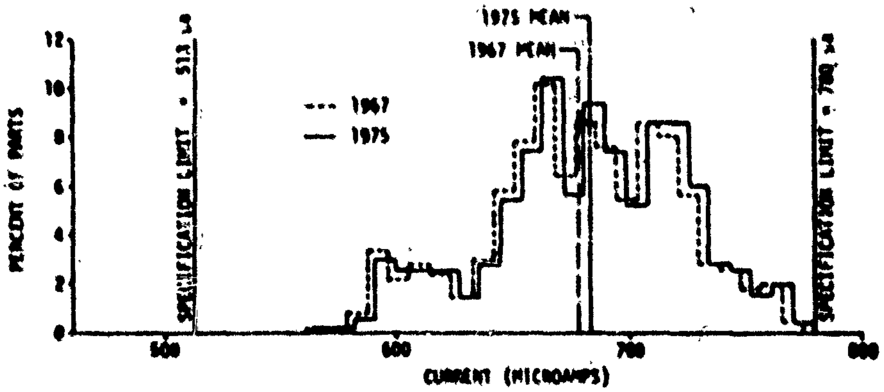
1.1 SUMMARY (Continued)



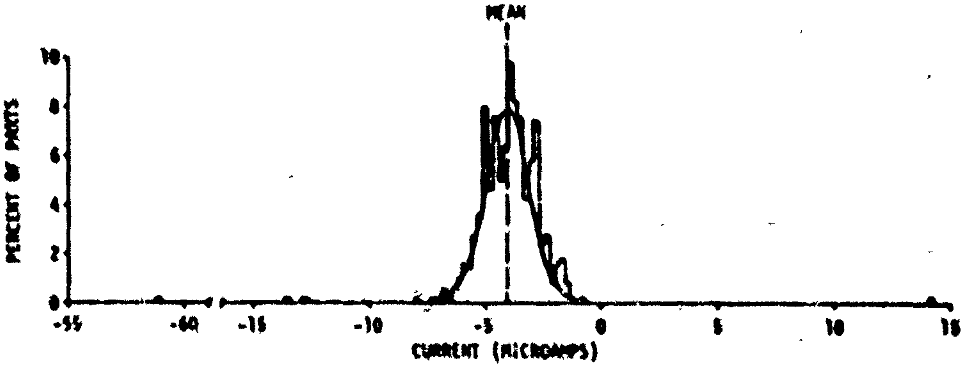
a. SCHEMATIC FOR I_{OUT} (7) TEST (R_1 RESISTANCE CHECK)

NO. OF PARTS REPRESENTED BY HISTOGRAM 800

TEST	MEAN	STD DEV.
1967	679 μA	42.5 μA
1975	683 μA	42.5 μA
1967-1975 DELTA	-4 μA	3.0 μA



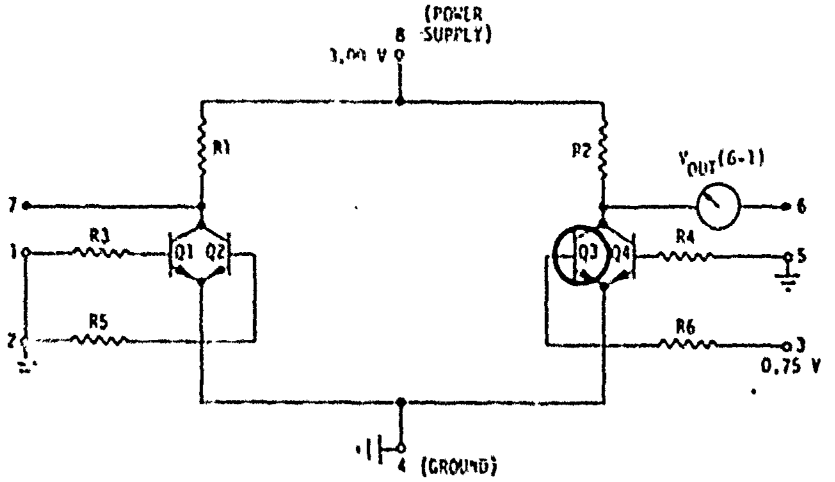
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



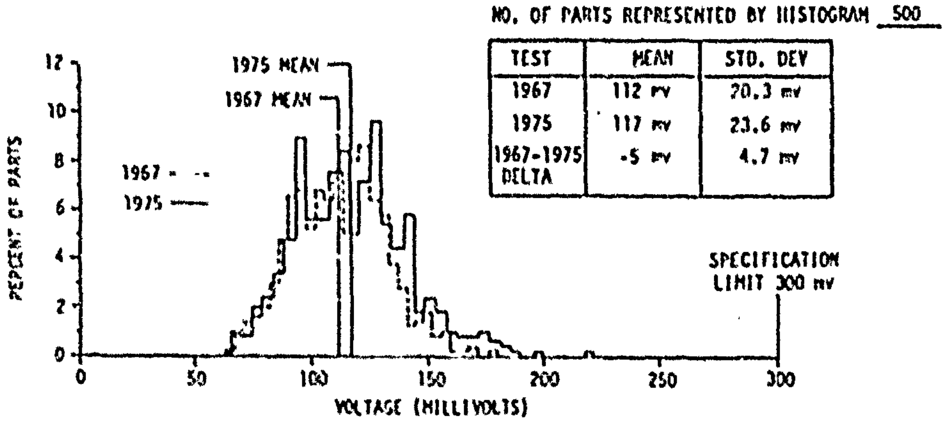
c. 1967-1975 CHANGE IN I_{OUT} (7)

FIGURE 1-2. HISTOGRAM COMPARISON OF I_{OUT} (7)
- DOUBLE GATE -

1.1 SUMMARY (Continued)



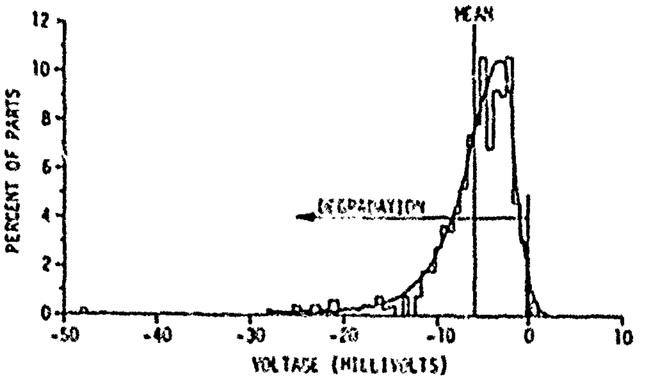
a. SCHEMATIC FOR V_{OUT}(6-1) TEST (Q3 VOLTAGE DROP AT MINIMUM "ON" CONDITION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 500

TEST	MEAN	STD. DEV
1967	112 mv	20.3 mv
1975	117 mv	23.6 mv
1967-1975 DELTA	-5 mv	4.7 mv

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

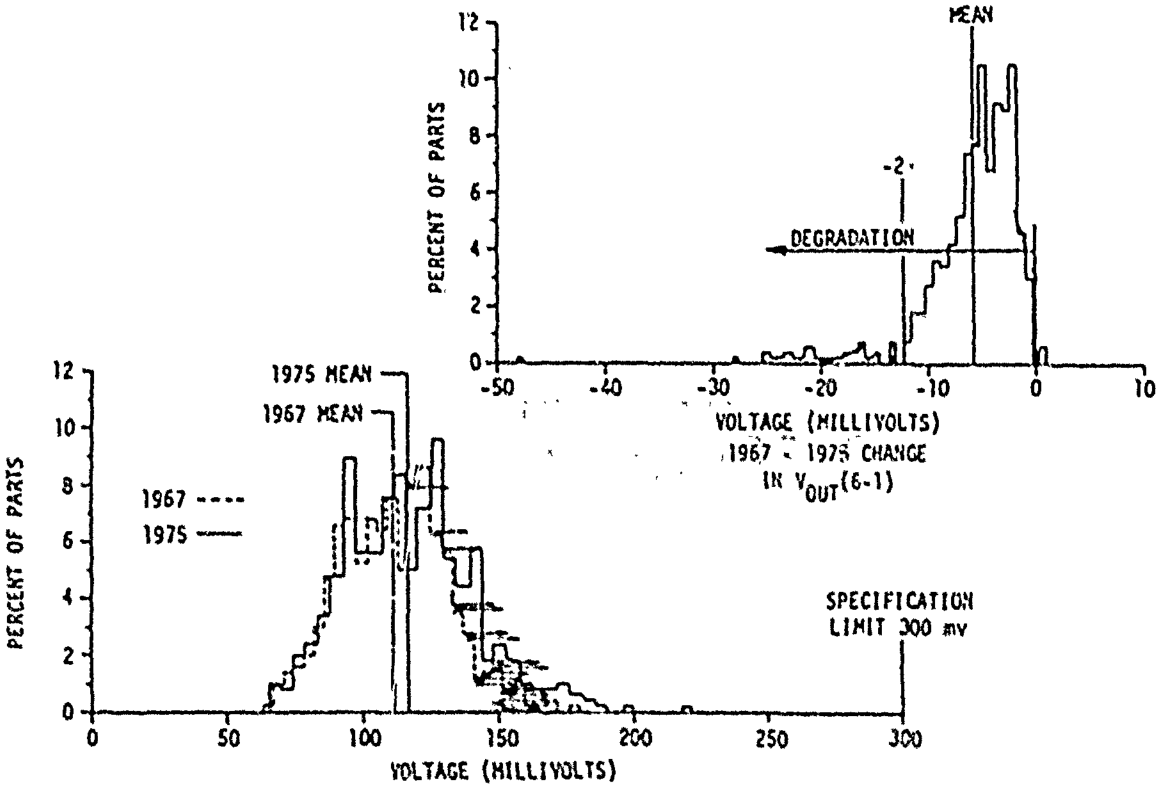


c. 1967 - 1975 CHANGE IN V_{OUT}(6-1)

FIGURE 1-3. HISTOGRAM COMPARISON OF V_{OUT}(6-1)

- DOUBLE GATE -

1.1 SUMMARY (Continued)



d. DISTRIBUTION OF PARTS SHOWING GREATEST DEGRADATION

FIGURE 1-3. (CONTINUED)

The loss of performance in the transistor elements was significant enough to class 24 parts as incipient failures. These are parts whose performance has degraded near specification limits and could fall out of spec within the next few years of storage. Since the Parameter Drift study measured only one of the two output terminals on each part, and only 2573 of the 10,027 parts (1/2 x 2573/10027 ≈ 1/8 sample), it can be reasonably expected that 8x24≈200 of the 10,027 parts (approximately 2%) are likely incipient failures.

1.1 SUMMARY (CONTINUED)

The degradation in transistor performance as demonstrated by an increase in both mean and standard deviation, was statistically significant at the 99% confidence level for the Double Gate, Register and Expander devices. These devices showed drift rates of 0.5-1% per year in mean value and 2-4% per year in standard deviation. The lower figures apply to the Double Gate and Register, while the higher figures apply to the Expander. A linear model (constant rate of drift) was fit to the mean and standard deviation measured on these devices. Figure 1-4 below shows this model for the Expander. This linear model predicts that a part whose 1967 performance was more than 3 standard deviations below the mean would drift out of specification limits after 17 years of storage (by 1984).

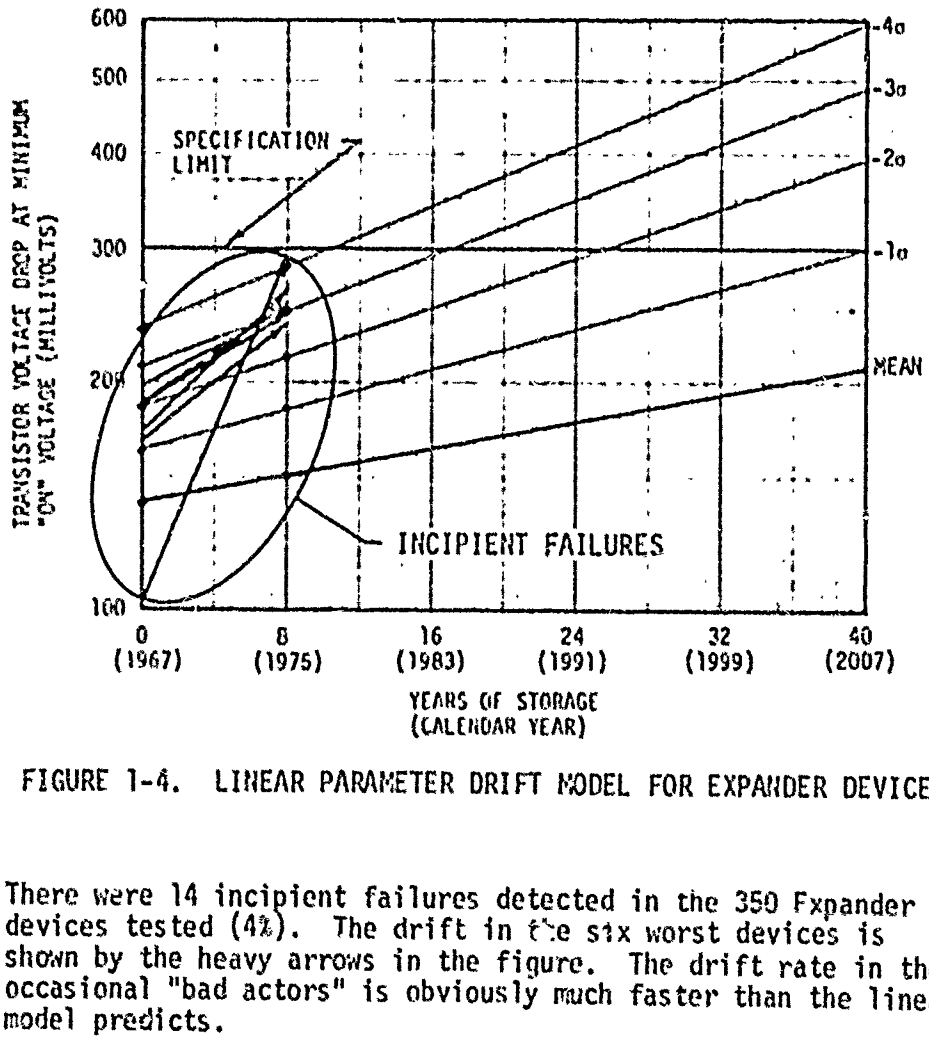


FIGURE 1-4. LINEAR PARAMETER DRIFT MODEL FOR EXPANDER DEVICES

There were 14 incipient failures detected in the 350 Expander devices tested (4%). The drift in the six worst devices is shown by the heavy arrows in the figure. The drift rate in these occasional "bad actors" is obviously much faster than the linear model predicts.

1.1 (Continued)

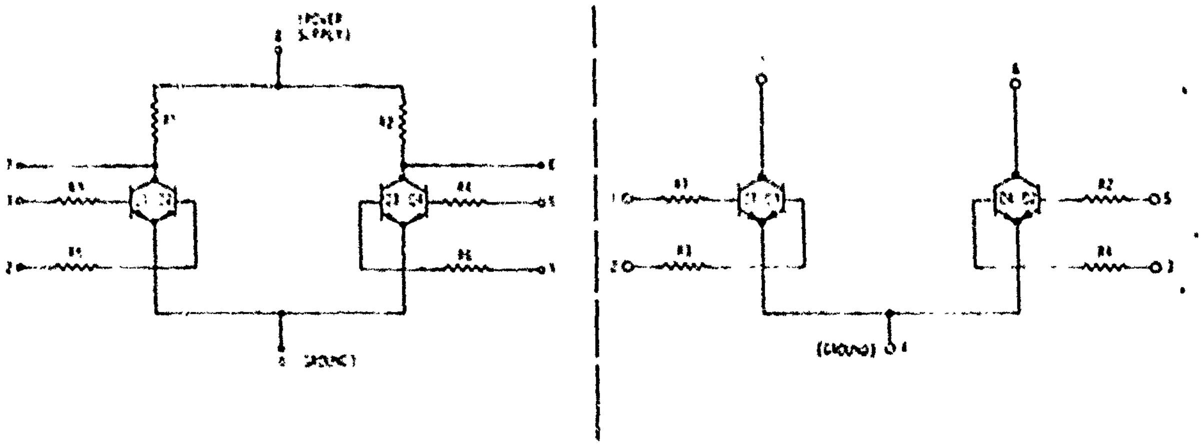
Whether a linear model provides a useful projection of parameter drift characteristics can only be determined by future testing of the same parts. However, the general trend of increasing rate of drift for the higher negative σ parts (poorer performers) is clearly established by the data from the 1975 test. This trend leads to the conclusion that storage reliability of these chip and bond wire devices can be increased by simply rejecting the more marginal performers during initial acceptance testing. In the case of the Expander parts, all but one of the 14 incipient failures would have been eliminated by rejecting the 16% of the parts that fell more than one standard deviation (-1σ) below the mean following the 1967 acceptance testing. Eight of the 14 would have been eliminated by a -2σ criterion, which would have required rejecting only 2.3% of the parts.

SECTION 2

FAILURE RATE ANALYSIS

2.0 INTRODUCTION

To determine the shelf-life failure rate of bond wire RTL Integrated Circuits (IC's), 10,027 such devices, stored for eight years, were retested to the 25°C parametric limits of the Boeing specifications. The parts were tested to these specifications by the supplier (Motorola) eight years ago. Retesting was done on a model J283C Teradyne Test Set, programmed, calibrated and maintained by the Boeing Advanced Electronic Design Group. Each of the 10,027 IC's was tested on a GO NO-GO basis to determine if one or more of its parameters had drifted outside specification limits. Those parts which failed the GO NO-GO testing on the Teradyne were carefully rechecked on the bench to verify their condition. Out of the more than 10,000 parts tested, only three defectives were found. The three were catastrophic failures with several parameters more than two orders of magnitude outside specification limits. The failures occurred in the Double Gate and Expander devices, whose circuit schematics are shown below.



DOUBLE GATE

EXPANDER

FIGURE 2-1. CIRCUIT SCHEMATICS FOR FAILED PARTS

2.1 FAILURE ANALYSIS

The three catastrophic failures were subjected to analysis to determine the cause of failure. They were first given a hermetic seal test with the following results:

TABLE 2-I. LEAK TEST RESULTS

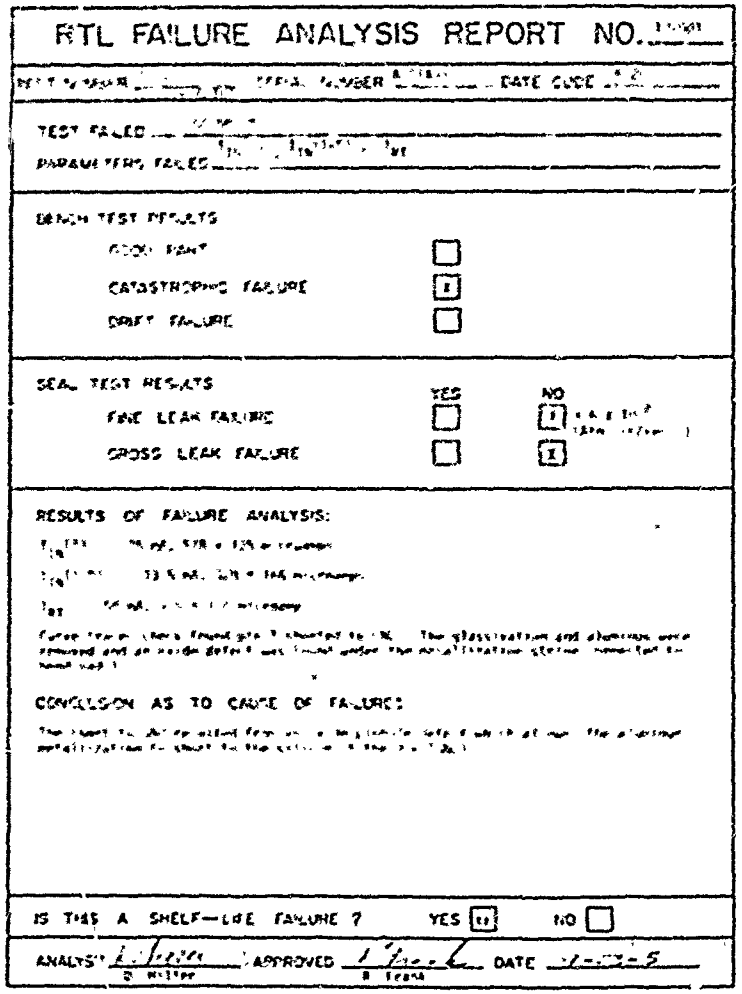
LOGIC FUNCTION	PART NO	GROSS LEAK	*FINE LEAK RATE	*SPECIFICATION VALUE
Double Gate	1493	No	3.6×10^{-8} cc/sec	$<1 \times 10^{-8}$ cc/sec
Expander	228	No	9.81×10^{-8} cc/sec	"
Expander	561	No	2.19×10^{-8} cc/sec	"

*@25°C and one standard atmosphere

While the measured fine leak rates exceeded specification, they were still small enough to conclude that no significant breakdown had occurred in the hermetic seals. The defects identified by subsequent failure analyses were in no way aggrevated by leakage.

Curve tracer testing of the three parts [checking from each lead to the ground (GND) lead and to the power supply lead with a Tektronix 577 Curve Tracer Oscilloscope] found a low resistance path from pin 1 (input) to pin 4 (GND) on Part No. 1493, a 100 ohm "short" from pin 3 (input) to pin 4 on Part No. 228, and a 600 ohm path from pin 6 (output) to pin 4 (GND) on Part No. 561. Experience with transistor-transistor logic devices has shown that such low resistance paths to GND (substrate of the die) occur because of oxide defects or because the part has been subjected to electrical overstress. To determine if the failures were due to oxide effects or electrical overstress, the three IC's were delidded and microscopically examined. No gross defects were observed such as might be caused by electrical overstress so the glassivation was removed from each die using buffered hydrofluoric acid. Next the aluminum metallization was removed with dilute sodium hydroxide. It was then easy to see that the failures were due to defects in the oxide which had allowed the metallization to short through to the active silicon of the die. There was an oxide defect/pinhole under an aluminization stripe connected to the No. 1 bond pad on Part No. 1493, under the No. 3 bond pad on Part No. 228, and under the No. 6 bond pad on Part No. 561. Based on the above analyses, it was concluded that the three failures were the result of deficiencies within the parts and were not caused by externally applied overstress and therefore that the three failures had to be considered shelf-life failures. The failure analysis reports are shown in Tables 2-II through 2-IV.

TABLE 2-II. FAILURE ANALYSIS REPORT FOR DOUBLE GATE PART NO. 1493



RTL FAILURE ANALYSIS REPORT NO. [illegible]

PART NUMBER [illegible] SERIAL NUMBER [illegible] DATE CODE [illegible]

TEST FAILED [illegible]

PARAMETERS FAILED [illegible]

BENCH TEST RESULTS

GOOD PART	☐
CATASTROPHIC FAILURE	☒
DRIFT FAILURE	☐

SEAL TEST RESULTS

	YES	NO
FINE LEAK FAILURE	☐	☒ [illegible]
GROSS LEAK FAILURE	☐	☒

RESULTS OF FAILURE ANALYSIS:

[illegible]

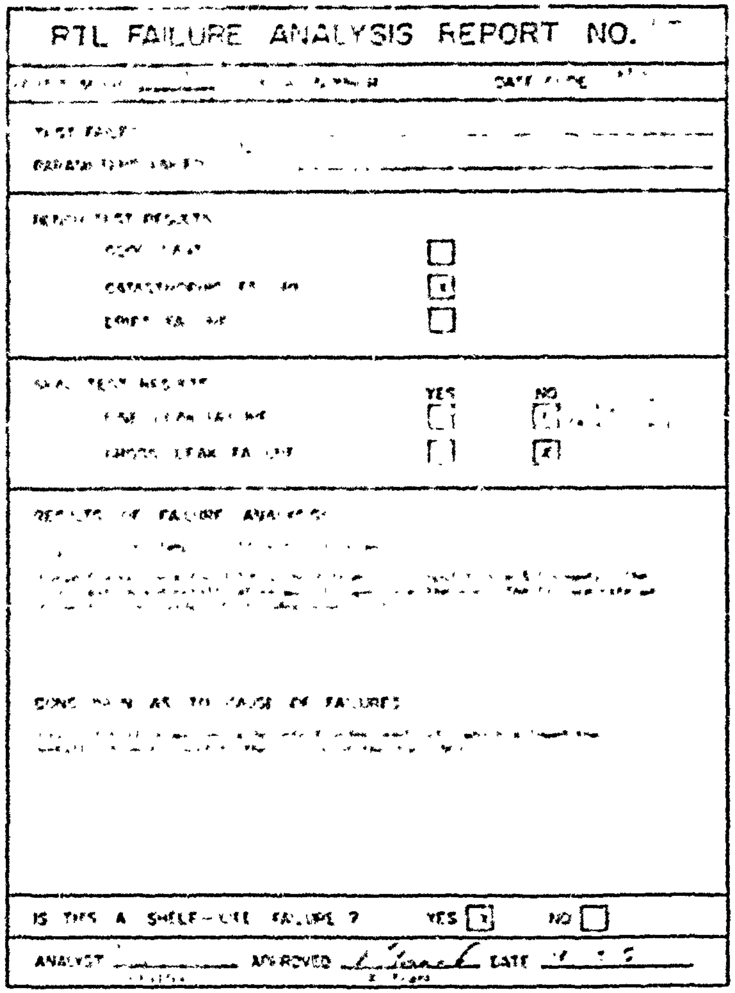
CONCLUSION AS TO CAUSE OF FAILURE:

[illegible]

IS THIS A SHELF-LIFE FAILURE ? YES ☒ NO ☐

ANALYST [illegible] APPROVED [illegible] DATE [illegible]

TABLE 2-III. FAILURE ANALYSIS REPORT FOR EXPANDER PART NO. 228



RTL FAILURE ANALYSIS REPORT NO. [illegible]

PART NUMBER [illegible] SERIAL NUMBER [illegible] DATE CODE [illegible]

TEST FAILED [illegible]

PARAMETERS FAILED [illegible]

BENCH TEST RESULTS

GOOD PART	☐
CATASTROPHIC FAILURE	☒
DRIFT FAILURE	☐

SEAL TEST RESULTS

	YES	NO
FINE LEAK FAILURE	☐	☒ [illegible]
GROSS LEAK FAILURE	☐	☒

RESULTS OF FAILURE ANALYSIS:

[illegible]

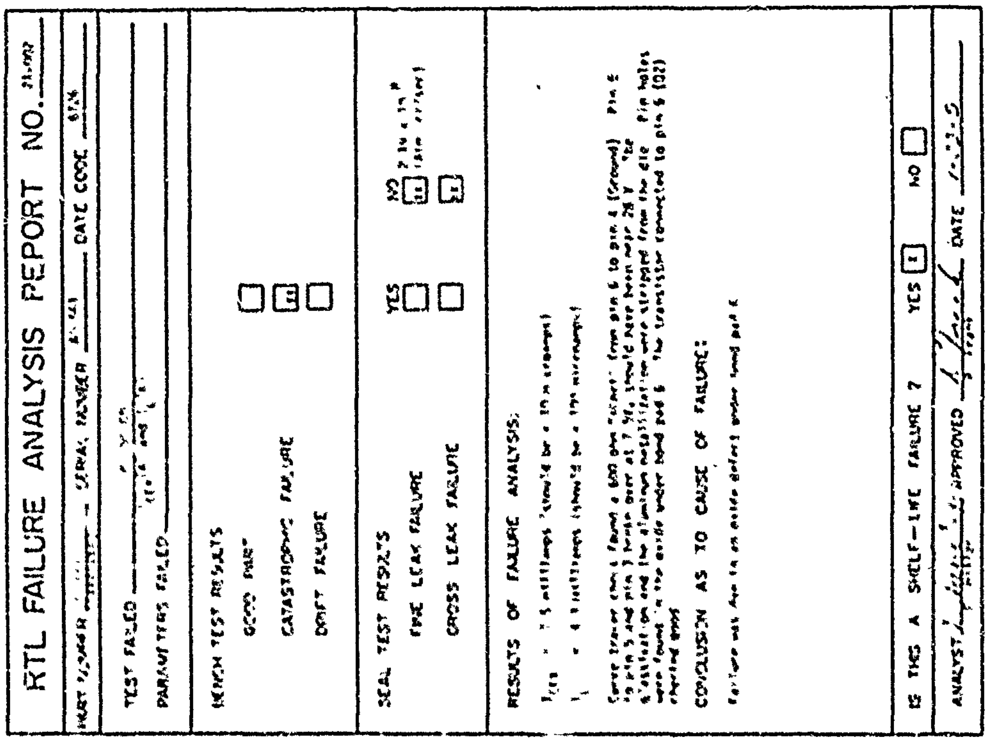
CONCLUSION AS TO CAUSE OF FAILURE:

[illegible]

IS THIS A SHELF-LIFE FAILURE ? YES ☒ NO ☐

ANALYST [illegible] APPROVED [illegible] DATE [illegible]

TABLE 2-IV. FAILURE ANALYSIS REPORT FOR EXPANDER PART NO. 561



RTL FAILURE ANALYSIS PEPORT NO. [illegible]

PART NUMBER [illegible] - SERIAL NUMBER [illegible] DATE CODE [illegible]

TEST FAILED [illegible]

PARAMETERS FAILED [illegible]

BENCH TEST RESULTS

GOOD PART ☐

CATASTROPHIC FAILURE ☒

DRIFT FAILURE ☐

SEAL TEST RESULTS	YES	NO
FINE LEAK FAILURE	☐	☒ [illegible]
GROSS LEAK FAILURE	☐	☒

RESULTS OF FAILURE ANALYSIS:

I_{CEO} = [illegible] milliamps (should be < [illegible])

I_{I} = [illegible] milliamps (should be < [illegible])

Curve tracer check found a 600 ohm "short" from pin 6 to pin 4 (Ground). Pin 6 to pin 5 and pin 3 broke over at 7 V, should have been near 28 V. The glassivation and the aluminum metallization were stripped from the die. Pin holes were found in the oxide under bond pad 6. The transistor connected to pin 6 (Q2) checked good.

CONCLUSION AS TO CAUSE OF FAILURE:

Failure was due to an oxide defect under bond pad 6.

IS THIS A SHELF-LIFE FAILURE ? YES ☒ NO ☐

ANALYST [illegible] APPROVED [illegible] DATE [illegible]

Oxide defects in general result from manufacturing deficiencies during wafer fabrication and in some instances during die probe or during wire bonding. Such things as holes and/or tears in the masks used for exposing the photoresist or foreign particles on the wafer during oxide growth can cause defects in the oxide. These defects are harmful only when they occur under the metallization pattern and only if they allow the metal to short through the oxide to the active silicon beneath. Improvements in manufacturing techniques are possible which can reduce the number of oxide defects and therefore the number of failures. Very careful cleaning procedures before growing the oxides and a double mask set used during the exposure of the photoresist prior to etching the oxides will produce parts with fewer defects. Many manufacturers, though, are reluctant to change historic and generally accepted manufacturing techniques to attempt to produce defect-free parts. In most programs, the cost of such parts is prohibitive so there is little incentive to improve an already acceptable failure rate.

It is not possible to tell at what point in time the oxide defect failures occurred. Since the defects (holes) found in the oxide were relatively large, it is difficult to explain why the deposited aluminization did not make intimate contact with the substrate silicon when the wafer was metallized during manufacture. If a very thin layer of oxide existed to insulate the aluminum from the silicon substrate, what eventually occurred to cause the short? It is possible that a very thin layer of oxide could

2.1 (Continued)

sustain the burn-in and test voltage stresses at Motorola and then chemically change with age to become a low resistance path to substrate silicon. In any event, experience in Minuteman has shown that most oxide defect failures occur either in receiving inspection testing or in equipment test after the IC's are installed on circuit cards. Though oxide defects are the most prevalent cause of failure in the low power transistor-transistor logic (TTL) deviced used in Minuteman, the failures occur and are eliminated during receiving testing or during functional test at the circuit card level rather than during field operation of the equipment. Nearly 0.04% of the TTL devices obtained from four different suppliers fail due to oxide defects prior to field installation of the equipment, but with more than 200,000 TTL devices fielded, some for more than two years, the number of failures due to oxide defects is at least an order of magnitude less than during receiving/functional test. This means that in actual hardware applications, most oxide defect parts would be detected and eliminated prior to storage by assuring that adequate functional tests are carried out at the circuit card or subsystem level.

2.2 FAILURE RATE AND MTBF

Since there were no parameter drift failures in the 10,027 parts after eight years of storage, the three catastrophic failures were used to compute the failure rate statistics. The Chi Square (χ^2) distribution was used to determine the 60% and 90% confidence level for failure rate and MTBF. Use of the χ^2 distribution to establish confidence limits is treated in any standard text on statistics. The computations are presented in Equations 2-1 and 2-2.

FAILURE RATE

60% Confidence:

$$FR_{60\%} = \frac{\chi^2_{60\%} \times 3 \text{ failures}}{10{,}027 \text{ parts} \times 8 \text{ yrs/part} \times 8760 \text{ hr/yr}}$$

$$= \frac{4.175 \text{ failures}}{703 \times 10^6 \text{ hrs}} = 0.0059 \times 10^{-6} \text{ failures/hr} \qquad (2\text{-1a})$$

$$FR_{90\%} = \frac{\chi^2_{90\%} \times 3 \text{ failures}}{703 \times 10^6 \text{ hrs}} = \frac{6.70 \text{ failures}}{703 \times 10^6 \text{ hrs}} = 0.0095 \times 10^{-6} \text{ failures/hr} \qquad (2\text{-1b})$$

2.2 (Continued)

MEAN TIME BETWEEN FAILURES

$$MTBF_{60\%} = \frac{1}{FR_{60\%}} = \frac{1}{0.0059x10^{-6}} = 169 \times 10^6 \text{ hrs} \qquad (2\text{-}2a)$$

$$MTBF_{90\%} = \frac{1}{FR_{90\%}} = \frac{1}{0.0095x10^{-6}} = 105 \times 10^6 \text{ hrs} \qquad (2\text{-}2b)$$

The design, manufacture, and test procedures used to develop these parts has obviously produced IC's of very high storage reliability. After eight years of storage, there were no parameter drift failures, no bond wire failures, no external leads corroded or broken, and no package problems. As already discussed, in an actual hardware application the three oxide defects that did occur would likely have been eliminated by assuring that normal functional tests were conducted following installation of the IC's on circuit cards.

SECTION 3

PARAMETER DRIFT ANALYSIS

3.0 INTRODUCTION

The Parameter Drift Test Program measured up to seven different parameters on each of the seven types of logic function devices. Table 3-I shows the 45 individual parameter tests that were performed on a total of 2573 parts. The physical characteristics associated with each parameter measurement (resistance, transistor voltage drop, leakage current) are defined in the right hand column of the table. The 2573 parts tested were selected at random in blocks of 20 or less from the total 10027 part inventory.

TABLE 3-I. PARAMETER DRIFT TEST MATRIX

	LOGIC FUNCTION AND NO. OF PARTS TESTED (2573 PARTS TOTAL)							
PARAMETER	TWIN BUFFER (230 PARTS)	ADDER (250 PARTS)	DOUBLE GATE (570 PARTS)	4-INPUT GATE (340 PARTS)	HALF ADDER (250 PARTS)	REGISTER (625 PARTS)	EXPANDER (350 PARTS)	CHARACTERISTICS MEASURED
INPUT CURRENT I_{IN}	$I_{IN}(1)$	$I_{IN}(1)$	$I_{IN}(1)$	$I_{IN}(1)$	$I_{IN}(3)$ $I_{IN}(3)$	$I_{IN}(2)$	$I_{IN}(1)$	RESISTANCE PLUS BASE EMITTER PERFORMANCE AT SATURATION VOLTAGE
OUTPUT CURRENT I_{OUT}	$I_{OUT}(7)$	$I_{OUT}(6)$ $I_{OUT}(7-1)$	$I_{OUT}(7)$	$I_{OUT}(7)$	$I_{OUT}(7-1)$	$I_{OUT}(6-1)$	NO TEST	RESISTANCE
OUTPUT VOLTAGE V_{OUT}	$V_{OUT}(7-1)$	NO TEST	$V_{OUT}(6-1)$	$V_{OUT}(6-1)$	NO TEST	$V_{OUT}(5-1)$	$V_{OUT}(6-1)$	TRANSISTOR VOLTAGE DROP AT MINIMUM "ON" BASE EMITTER VOLTAGE
OUTPUT VOLTAGE V_{CE}	$V_{CE}(7-1)$	$V_{CE}(7-1)$	$V_{CE}(6-1)$ $V_{CE}(7-1)$	$V_{CE}(6-1)$	$V_{CE}(6)$	$V_{CE}(6-1)$	$V_{CE}(6-1)$ $V_{CE}(7-1)$	TRANSISTOR VOLTAGE DROP AT SATURATION VOLTAGE
LEAKAGE CURRENT I_{BX}	$I_{BX}(1-2)$ $I_{BX}(3-5)$	$I_{BX}(1,2,3,5)$	I_{BX}	I_{BX}	I_{BX}	I_{BX}	$I_{BX}(1,2,3,5)$	BASE EMITTER JUNCTION LEAKAGE CHARACTERISTICS
LEAKAGE CURRENT I_L	$I_L(8)$	$I_L(8)$	$I_L(8)$	$I_L(8)$	$I_L(8)$	$I_L(8)$	$I_L(6,7,8)$	TRANSISTOR LEAKAGE CHARACTERISTICS AT ZERO BASE EMITTER VOLTAGE
LEAKAGE CURRENT I_{CEX}	NO TEST	NO TEST	NO TEST	NO TEST	NO TEST	NO TEST	$I_{CEX}(7)$	TRANSISTOR LEAKAGE CHARACTERISTICS AT MAXIMUM "OFF" BASE EMITTER VOLTAGE

NOTE NO. IN PARENTHESES DESIGNATES PIN BEING SENSED, AND TEST CONDITIONS BEING IMPOSED. THESE CONDITIONS ARE DEFINED IN SECTION 3.4

Section 3.1 summarizes Parameter Drift results with emphasis on pinpointing the physical elements within each device most susceptible to aging. Section 3.2 provides a histogram comparison of the 1967 and 1975 test results for each of the 45 parameter tests defined above.

3.1 PARAMETER DRIFT SUMMARY

Tables 3-II through 3-VIII summarize the Test Results for the seven parameters that were measured to evaluate drift. Each table compares the 1967 and 1975 mean values and standard deviations for a single parameter, starting with I_{IN} (Table 3-II). The 1967-1975 changes in the mean value and standard deviation were tested for statistical significance via the Student t and F-Distribution tests, respectively. These two tests are covered in all standard texts on Statistics. Tests of significance determine the likelyhood that the observed changes are due to random sampling differences (in this case, measurement errors) rather than to true drift. The conservative criterion of 99% confidence was adopted for these tests. This means that there is less than a one percent chance that the 1967-1975 change in any parameter that fails this criterion could be explained by measurement errors alone (or conversely, there is 99% confidence that parameter drift has occurred). The "Analysis of Change" columns at the right of each table show the results of these statistical tests of significance.

The two most useful parameters proved to be I_{OUT} (Table 3-III) and V_{OUT} (Table 3-IV), which directly measure changes in resistor and transistor characteristics, respectively. The V_{OUT} measurement is the most sensitive of the transistor measurements, since it determines voltage drop across the transistor under conditions of minimum "on" base emitter voltage. This "knee-of-the-curve" operational condition provided the clearest picture of storage-induced changes in the transistor elements. The I_{IN} and V_{OL} measurements (Tables 3-II and 3-V), while not as sensitive as the V_{OUT} measurements, also provided supportive data on transistor drift. Little quantitative information was obtained from the leakage current measurements, I_{RT}, I_L, and I_{CEX} (Tables 3-VI thru 3-VIII), since the 1967 tests were not carried out to the nanoamp precision needed to define changes in these parameters. However, the 1975 measurements showed that leakage rates were insignificant compared with specification values and that drift in these parameters was negligible.

As discussed in Section 1, there was no measurable degradation in the resistor elements after eight years of storage. However, the degradation in transistor performance was significant at the 95% confidence level for all six logic function devices on which V_{OUT} measurements were taken. In three of these families, the Double Gate, the Register, and the Expander, changes were significant at the 99% confidence level, as indicated by the boxed-in values in Table 2-IV. The statistics for the Double Gate and Register were similar enough to combine these two families, which gives the bottom row in Table 3-III.

TABLE 3-II SUMMARY OF I_{IN} PARAMETER DRIFT

LOGIC FUNCTION	PARAMETER *(REF)	SAMPLE SIZE N	MEASURED PERFORMANCE (μa) 1967 TEST $\bar{x}$	MEASURED PERFORMANCE (μa) 1967 TEST σ	MEASURED PERFORMANCE (μa) 1975 TEST $\bar{x}$	MEASURED PERFORMANCE (μa) 1975 TEST σ	1967 - 1975 CHANGE (μa) $\Delta\bar{x}$	1967 - 1975 CHANGE (μa) $\Delta\sigma$	SPECIFICATION LIMIT (μa)	ANALYSIS OF CHANGE $\bar{x}$ $t_{\bar{x}}$	ANALYSIS OF CHANGE $\bar{x}$ t_{99}	ANALYSIS OF CHANGE σ F_σ	ANALYSIS OF CHANGE σ F_{99}
TWIN BUFFER	$I_{IN}(3)$ (Fig. 3-3)	250	185	10.0	181	9.5	**	**	<250	**		**	
ADDER	$I_{IN}(1)$ (Fig. 3-10)	250	88.0	6.4	86.4	6.3	↓	↓	<125	↓		↓	
DOUBLE GATE	$I_{IN}(1)$ (Fig. 3-15)	500	98.2	4.9	95.2	5.4	↓	↓	↓	↓		↓	
4-INPUT GATE	$I_{IN}(1)$ (Fig. 3-22)	348	83.5	3.8	82.5	3.8	↓	↓	↓	↓		↓	
HALF ADDER	$I_{IN}(1)$ (Fig. 3-28)	250	90.1	4.9	89.0	4.7	↓	↓	↓	↓		↓	
	$I_{IN}(3)$ (Fig. 3-29)	250	89.7	4.6	88.6	4.4	↓	↓	↓	↓		↓	
REGISTER	$I_{IN}(2)$ (Fig. 3-34)	625	76.4	6.3	91.3	5.2	↓	↓	↓	↓		↓	
EXPANDER	$I_{IN}(1)$ (Fig. 3-40)	350	114.8	6.3	122.9	6.5	↓	↓	<166	↓		↓	

* FIGURE NO. OF PLOTTED RESULTS

$\bar{x}$ = MEAN

σ = STANDARD DEVIATION

$\Delta\bar{x}$ = 1967-1975 CHANGE IN MEAN

$\Delta\sigma$ = 1967-1975 CHANGE IN STANDARD DEVIATION

☐ CHANGE SIGNIFICANT AT 99% CONFIDENCE LEVEL

$$t_{\bar{x}} = \Delta\bar{x}\sqrt{\frac{N}{\sigma_{67}^2 + \sigma_{75}^2}}$$

$$F_\sigma = \frac{\sigma_{75}^2}{\sigma_{67}^2}$$

t_{99} = 99% PROBABILITY LEVEL FROM STUDENT t DISTRIBUTION

F_{99} = 99% PROBABILITY LEVEL FROM F-DISTRIBUTION

** = NO STATISTICALLY SIGNIFICANT CHANGE - DIFFERENCES ATTRIBUTED TO NORMAL OBSERVATION ERROR

TABLE 3-III SUMMARY OF I_{OUT} PARAMETER DRIFT
(RESISTOR PERFORMANCE)

LOGIC FUNCTION	PARAMETER *(REF)	SAMPLE SIZE N	MEASURED PERFORMANCE (μa)				1967 - 1975 CHANGE (μa)		SPECIFICATION LIMIT(S) (μa)	ANALYSIS OF CHANGE			
			1967 TEST		1975 TEST					$\bar{x}$		σ	
			$\bar{x}$	σ	$\bar{x}$	σ	$\Delta\bar{x}$	$\Delta\sigma$		$t_{\bar{x}}$	t_{99}	F_σ	F_{99}
TWIN BUFFER	$I_{OUT}(7)$ (Fig. 3-4)	250	18900	700	19000	700	**	**	> 4030	**		**	
ADDER	$I_{OUT}(6)$ (Fig. 3-11)	250	556	59	561	59	↓	↓	> 513	↓		↓	
	$I_{OUT}(7-1)$ (Fig. 3-11a)	250	644	64	648	64	↓	↓	>513	↓		↓	
DOUBLE GATE	$I_{OUT}(7)$ (Fig. 3-16)	500	679	43	683	43	↓	↓	> 513 AND < 780	↓		↓	
4-INPUT GATE	$I_{OUT}(7)$ (Fig. 3-23)	348	574	34	577	34	↓	↓	> 513	↓		↓	
HALF ADDER	$I_{OUT}(7-1)$ (Fig. 3-30)	250	598	36	601	38	↓	↓	> 405	↓		↓	
REGISTER	$I_{OUT}(6-1)$ (Fig. 3-35)	625	521	41	533	38	↓	↓	> 405	↓		↓	

* FIGURE NO. OF PLOTTED RESULTS

$\bar{x}$ = MEAN

σ = STANDARD DEVIATION

$\Delta\bar{x}$ = 1967-1975 CHANGE IN MEAN

$\Delta\sigma$ = 1967-1975 CHANGE IN STANDARD DEVIATION

☐ CHANGE SIGNIFICANT AT 99% CONFIDENCE LEVEL

$$t_{\bar{x}} = \Delta\bar{x}\sqrt{\frac{N}{\sigma_{67}^2 + \sigma_{75}^2}}$$

$$F_\sigma = \frac{\sigma_{75}^2}{\sigma_{67}^2}$$

t_{99} = 99% PROBABILITY LEVEL FROM STUDENT t DISTRIBUTION

F_{99} = 99% PROBABILITY LEVEL FROM F-DISTRIBUTION

** = NO STATISTICALLY SIGNIFICANT CHANGE - DIFFERENCES ATTRIBUTED TO NORMAL OBSERVATION ERROR

TABLE 3-IV SUMMARY OF V_{OUT} PARAMETER DRIFT (TRANSISTOR PERFORMANCE)

LOGIC FUNCTION	PARAMETER *(REF)	SAMPLE SIZE N	MEASURED PERFORMANCE (mv)				1967 - 1975 CHANGE (mv)		SPECIFICATION LIMIT (mv)	ANALYSIS OF CHANGE			
			1967 TEST		1975 TEST					$\bar{x}$		σ	
			$\bar{x}$	σ	$\bar{x}$	σ	$\Delta\bar{x}$	$\Delta\sigma$		t	t_{99}	F	F_{99}
TWIN BUFFER	$V_{OUT}(7-1)$ (Fig. 3-5)	250	103	17.7	107	20.7	+ 4	+ 2.4	< 300	2.4	2.3	1.3	1.4
DOUBLE GATE	$V_{OUT}(6-1)$ (Fig. 3-17)	500	112	20.3	117	23.6	+ 5	+ 3.3		$\boxed{3.6}$	2.3	$\boxed{1.4}$	1.2
4-INPUT GATE	$V_{OUT}(6-1)$ (Fig. 3-24)	348	94	18.0	97	19.6	+ 3	+ 1.6		2.1	2.3	1.2	1.3
REGISTER	$V_{OUT}(5-1)$ (Fig. 3-36)	625	110	21.8	114	24.2	+ 4	+ 2.5		$\boxed{3.1}$	2.3	$\boxed{1.2}$	1.2
EXPANDER	$V_{OUT}(6-1)$ (Fig. 3-41)	350	138	23.5	150	32.4	+12	+ 8.9		$\boxed{5.6}$	2.3	$\boxed{1.9}$	1.3
DOUBLE GATE + REGISTER	$V_{OUT}(6-1)$ $+V_{OUT}(5-1)$	1125	111	21.1	116	24.0	+ 5	+ 2.9		$\boxed{5.2}$	2.3	$\boxed{1.3}$	1.2

* FIGURE NO. OF PLOTTED RESULTS

$\bar{x}$ = MEAN

σ = STANDARD DEVIATION

$\Delta\bar{x}$ = 1967-1975 CHANGE IN MEAN

$\Delta\sigma$ = 1967-1975 CHANGE IN STANDARD DEVIATION

☐ STATISTICALLY SIGNIFICANT CHANGE AT 99% CONFIDENCE LEVEL

$$t_{\bar{x}} = \Delta\bar{x}\sqrt{\frac{N}{\sigma_{67}^2 + \sigma_{75}^2}}$$

$$F_\sigma = \frac{\sigma_{75}^2}{\sigma_{67}^2}$$

t_{99} = 99% PROBABILITY LEVEL FROM STUDENT t DISTRIBUTION

F_{99} = 99% PROBABILITY LEVEL FROM F-DISTRIBUTION

TABLE 3-V SUMMARY OF V_{OL} PARAMETER DRIFT

LOGIC FUNCTION	PARAMETER *(REF)	SAMPLE SIZE N	MEASURED PERFORMANCE (mv)				1967 - 1975 CHANGE (mv)		SPECIFICATION LIMIT (mv)	ANALYSIS OF CHANGE			
			1967 TEST		1975 TEST					$\bar{x}$		σ	
			$\bar{x}$	σ	$\bar{x}$	σ	$\Delta\bar{x}$	Δσ		$t_{\bar{x}}$	t_{99}	F_σ	F_{99}
TWIN BUFFER	$V_{OL}(7-1)$ Fig. 3-6	250	77.7	10.8	75.7	11.1	** ↓	** ↓	<200 ↓	** ↓		** ↓	
ADDER	$V_{OL}(7-1)$ Fig. 3-12	250	54.3	7.1	57.4	6.1							
DOUBLE GATE	$V_{OL}(6-1)$ Fig. 3-18	500	88.8	14.0	89.5	14.7							
	$V_{OL}(7-1)$ Fig. 3-19	500	89.5	14.1	90.7	15.0							
4-INPUT GATE	$V_{OL}(6-1)$ Fig. 3-25	348	73.9	11.1	74.1	11.4							
HALF ADDER	$V_{OL}(6)$ Fig. 3-31	250	93.5	13.8	91.9	13.9							
REGISTER	$V_{OL}(6-1)$ Fig. 3-37	625	89.2	14.8	90.5	15.7							
EXPANDER	$V_{OL}(6-1)$ Fig. 3-42	350	111.8	15.0	113.8	16.0							
	$V_{OL}(7-1)$ Fig. 3-43	350	112.7	14.8	115.3	16.0							

*FIGURE NO. OF PLOTTED RESULTS

$\bar{x}$ = MEAN

σ = STANDARD DEVIATION

$\Delta\bar{x}$ = 1967-1975 CHANGE IN MEAN

Δσ = 1967-1975 CHANGE IN STANDARD DEVIATION

☐ CHANGE SIGNIFICANT AT 99% CONFIDENCE LEVEL

$$t_{\bar{x}} = \Delta\bar{x}\sqrt{\frac{N}{\sigma_{67}^2 + \sigma_{75}^2}}$$

t_{99} = 99% PROBABILITY LEVEL FROM STUDENT t DISTRIBUTION

$$F_\sigma = \frac{\sigma_{75}^2}{\sigma_{67}^2}$$

F_{99} = 99% PROBABILITY LEVEL FROM F-DISTRIBUTION

** = NO STATISTICALLY SIGNIFICANT CHANGE - DIFFERENCES ATTRIBUTED TO NORMAL OBSERVATION ERROR

TABLE 3-VI SUMMARY OF I_{RT} PARAMETER DRIFT

LOGIC FUNCTION	PARAMETER *(REF)	SAMPLE SIZE N	MEASURED PERFORMANCE (μa)				1967 - 1975 CHANGE (μa)		SPECIFICATION LIMIT (μa)	ANALYSIS OF CHANGE			
			1967 TEST		1975 TEST					x		σ	
			$\bar{x}$	σ	$\bar{x}$	σ	$\Delta\bar{x}$	Δσ		$t_{\bar{x}}$	t_{99}	F_σ	F_{99}
TWIN BUFFER	I_{RT}(1-2) (Fig. 3-7)	250	0.013	0.017	0.026	0.035	**	**	<1	**		**	
	I_{RT}(3-5) (Fig. 3-8)	250	0.012	0.016	0.010	0.015							
ADDER	I_{RT}(1,2,3,5) (Fig. 3-13)	250	0.012	0.017	0.022	0.022							
DOUBLE GATE	I_{RT} (Fig. 3-20)	500	0.019	0.019	0.014	0.017							
4-INPUT GATE	I_{RT} (Fig. 3-26)	348	0.005	0.005	0.008	0.004							
HALF ADDER	I_{RT} (Fig. 3-32)	250	0.018	0.021	0.019	0.024							
REGISTER	I_{RT} (Fig. 3-38)	625	0.053	0.032	0.017	0.021							
EXPANDER	I_{RT} (Fig. 3-44)	350	0.006	0.002	0.001	0.001							

* FIGURE NO. OF PLOTTED RESULTS

$\bar{x}$ = MEAN

σ = STANDARD DEVIATION

$\Delta\bar{x}$ = 1967-1975 CHANGE IN MEAN

Δσ = 1967-1975 CHANGE IN STANDARD DEVIATION

$$t_{\bar{x}} = \Delta\bar{x}\sqrt{\frac{N}{\sigma_{67}^2 + \sigma_{75}^2}}$$

$$F_\sigma = \frac{\sigma_{75}^2}{\sigma_{67}^2}$$

t_{99} = 99% PROBABILITY LEVEL FROM STUDENT t DISTRIBUTION

F_{99} = 99% PROBABILITY LEVEL FROM F-DISTRIBUTION

** = NO MEANINGFUL CHANGE - MEASURED CHANGES ATTRIBUTED TO DIFFERENCES IN TEST

TABLE 3-VII SUMMARY OF I_L PARAMETER DRIFT

LOGIC FUNCTION	PARAMETER *(REF)	SAMPLE SIZE N	MEASURED PERFORMANCE (μa)				1967 - 1975 CHANGE (μa)		SPECIFICATION LIMIT (μa)	ANALYSIS OF CHANGE			
			1967 TEST		1975 TEST					$\bar{x}$		σ	
			$\bar{x}$	σ	$\bar{x}$	σ	$\Delta\bar{x}$	$\Delta\sigma$		$t_{\bar{x}}$	t_{99}	F_σ	F_{99}
TWIN BUFFER	$I_L(8)$ (Fig. 3-9)	250	0.4	0.4	2.3	1.3	** ↓	** ↓	<200	** ↓		** ↓	
ADDER	$I_L(8)$ (Fig. 3-14)	250	0.60	1.2	1.92	1.2			<100				
DOUBLE GATE	$I_L(8)$ (Fig. 3-21)	500	0.30	0.13	1.52	0.11			<100				
4-INPUT GATE	$I_L(8)$ (Fig. 3-27)	348	0.41	1.11	1.61	1.06			<100				
HALF ADDER	$I_L(8)$ (Fig. 3-33)	250	0.7	2.2	0.2	0.2			<100				
REGISTER	$I_L(8)$ (Fig. 3-39)	625	1.4	2.1	0.2	0.2			<100				
EXPANDER	$I_L(8)$ (Fig. 3-45)	350	0.30	0.002	0.13	0.06			<100				

* FIGURE NO. OF PLOTTED RESULTS

$\bar{x}$ = MEAN

σ = STANDARD DEVIATION

$\Delta\bar{x}$ = 1967-1975 CHANGE IN MEAN

$\Delta\sigma$ = 1967-1975 CHANGE IN STANDARD DEVIATION

$$t_{\bar{x}} = \Delta\bar{x}\sqrt{\frac{N}{\sigma_{67}^2 + \sigma_{75}^2}}$$

$$F_\sigma = \frac{\sigma_{75}^2}{\sigma_{67}^2}$$

t_{99} = 99% PROBABILITY LEVEL FROM STUDENT t DISTRIBUTION

F_{99} = 99% PROBABILITY LEVEL FROM F-DISTRIBUTION

** = NO MEANINGFUL CHANGE - MEASURED CHANGES ATTRIBUTED TO DIFFERENCES IN TEST PRECISION

TABLE 3-VIII SUMMARY OF I_{CEX} PARAMETER DRIFT

LOGIC FUNCTION	PARAMETER *(REF)	SAMPLE SIZE N	MEASURED PERFORMANCE (μa)				1967 - 1975 CHANGE (μa)		SPECIFICATION LIMIT (μa)	ANALYSIS OF CHANGE			
			1967 TEST		1975 TEST					$\bar{x}$		σ	
			$\bar{x}$	σ	$\bar{x}$	σ	$\Delta\bar{x}$	Δσ		$t_{\bar{x}}$	t_{99}	F_σ	F_{99}
EXPANDER	I_{CEX}(7) (Fig. 3-46)	350	0.68	0.43	0.58	0.37	**	**	<10	**		**	

* FIGURE NO. OF PLOTTED RESULTS

$\bar{x}$ = MEAN

σ = STANDARD DEVIATION

$\Delta\bar{x}$ = 1967-1975 CHANGE IN MEAN

Δσ = 1967-1975 CHANGE IN STANDARD DEVIATION

$$t_{\bar{x}} = \Delta\bar{x}\sqrt{\frac{N}{\sigma_{67}^2 + \sigma_{75}^2}}$$

$$F_\sigma = \frac{\sigma_{75}^2}{\sigma_{67}^2}$$

t_{99} = 99% PROBABILITY LEVEL FROM STUDENT t DISTRIBUTION

F_{99} = 99% PROBABILITY LEVEL FROM F-DISTRIBUTION

** = NO MEANINFGUL CHANGE - MEASURED CHANGES ATTRIBUTED TO DIFFERENCES IN TEST

3.1 (Continued)

Linear parameter drift rate models were developed for the Double Gate plus Register combined and the Expander. The Expander model has already been discussed in Section 1.1, Figure 1-4. The Double Gate/Register Model is plotted in Figure 3-1. The linear drift rate predicted for an average part is 1/2% per year, and for a -3σ part is 1% per year. These rates are about half those predicted for the Expander.

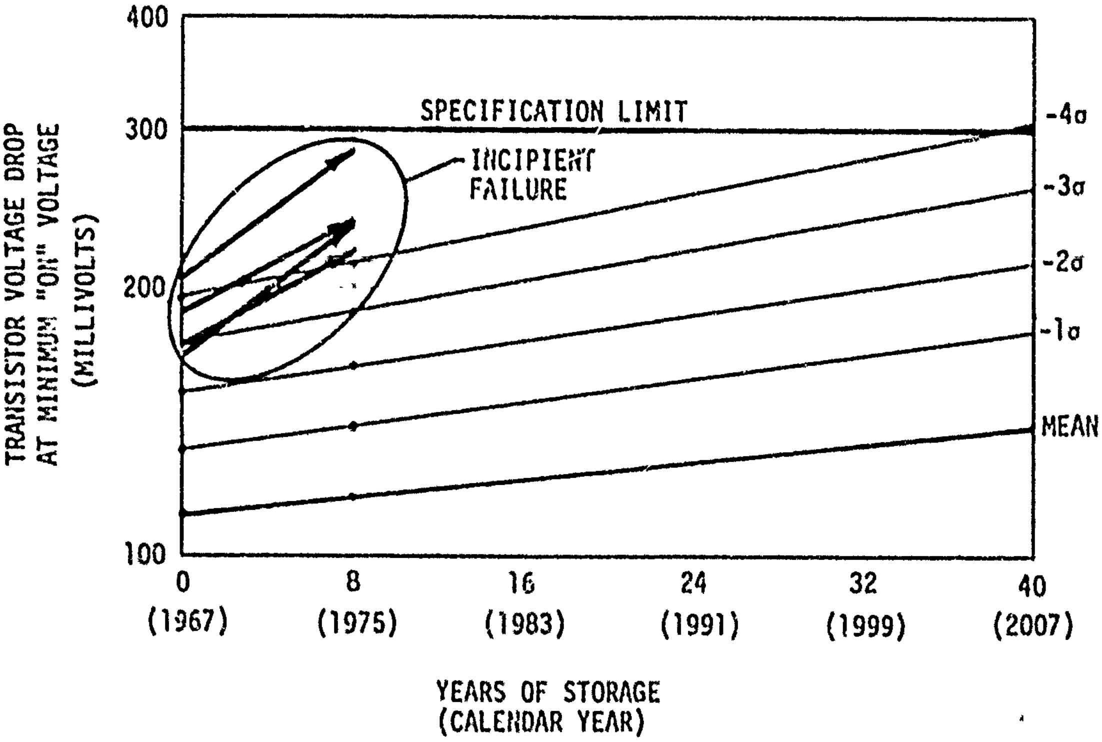


Figure 3-1. LINEAR PARAMETER DRIFT MODEL FOR DOUBLE GATE PLUS REGISTER

The four incipient failures from the Double Gate family are shown by the arrows in the figure. As was the case with the Expander, these incipient failures show a more rapid rate of drift than the linear model predicts for even a -4σ part. Extrapolating the linear model suggests that a -4σ part would not reach the 300mv specification limit until the turn of the century. The one -4σ incipient failure (uppermost arrow in the figure) has almost reached this limit after only eight years of storage.

3.1 (Continued)

A reason why parts with high V_{OUT} measurements should show the highest rates of drift can be deduced from Figure 3-2, which is a plot of V_{OUT} vs transistor gain. For above average (high gain, low V_{OUT}) parts, V_{OUT} is relatively insensitive to changes in transistor gain. A $+2\sigma$ part ($V_{OUT} < 71$ MV) shows only a 4 MV (5%) change in V_{OUT} for a 10% change in gain. For below average parts, however, V_{OUT} becomes increasingly sensitive to changes in gain. A -4σ part ($V_{OUT} > 193$ MV) shows a 36 MV (20%) change in V_{OUT} for a 10% change in gain. Transistor gain changes can occur because of growth of a "parasitic transistor" condition due to surface contamination, or to migration of the gold within the silicon lattice. Gold doping was used in these parts to suppress the parasitic transistor condition as well as to increase part reaction speed. These gain change mechanisms are discussed further in Section 4.

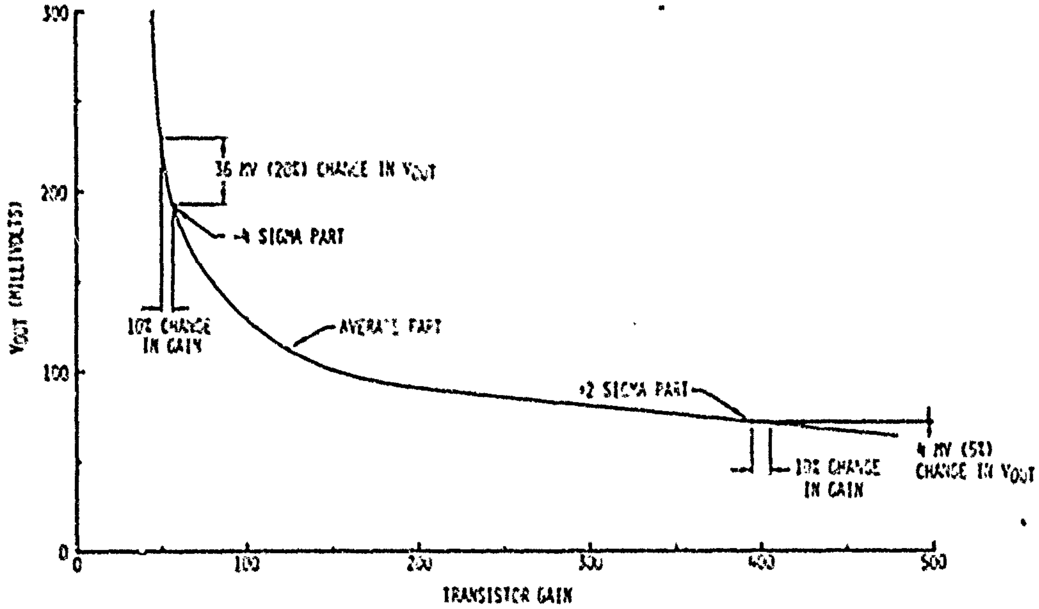


FIGURE 3-2. V_{OUT} PARAMETER VS. TRANSISTOR GAIN FOR DOUBLE GATE DEVICES

There were 24 parts out of the 2573 parts tested that showed large enough increases in V_{OUT} to class them as incipient failures. These parts are identified in Table 3-IX. As noted in Section 1.1, the V_{OUT} tests were performed on a 1/8 sample of the total part - output terminal population. Consequently, it is likely that approximately 200 incipient failures exist in the total of 10,027 parts.

The criteria for identifying a part as an "incipient failure" are: (1) the 1975 V_{OUT} value must exceed 220mv, and (2) the 1967-1975 increase in V_{OUT} must exceed 25mv. Of these 24 parts, all but one fell outside the -1σ limit during the 1967 tests. The lone exception is Part No. 1172 of the Expander family. Furthermore, all but 7 of the parts came from beyond the -2σ limit. These seven exceptions are also from the Expander Family (Part Nos. 1027, 1055, 1129, 1147, 1155, 1172, and 1201). *These statistics show that the shelf life of these parts could be significantly enhanced by rejecting parts whose performance falls more than one standard deviation below the mean.* This would mean rejecting about 16% of the parts.

3.1 (Continued)

TABLE 3-IX. INCIPIENT FAILURES

LOGIC FUNCTION	PART NO.	PARAMETER	TEST VALUE (mv) 1967	TEST VALUE (mv) 1975	PERCENT CHANGE	SPECIFICATION LIMIT (mv)
TWIN BUFFER	359	$V_{OUT}(7-1)$	161	229	42	300
	815	"	150	251	67	
	875	"	149	230	54	
	*965	"	172	207	20	
	*1229	"	165	231	40	
ADDER	NONE					
DOUBLE GATE	577	$V_{OUT}(6-1)$	169	238	40	
	*831	$V_{OUT}(7-1)$	189	238	26	
	1968	$V_{OUT}(6-1)$	172	220	28	
	*2452	$V_{OUT}(6-2)$	204	282	38	
4 INPUT GATE	*153	$V_{OUT}(6-4)$	178	277	56	
HALF ADDER	NONE					
REGISTER	NONE					
EXPANDER	1022	$V_{OUT}(6-1)$	172	234	36	
	1055	$V_{OUT}(6-1)$	174	264	52	
	*1067	$V_{OUT}(6-2)$	198	226	14	
	1093	$V_{OUT}(6-1)$	196	225	15	
	1123	"	189	247	31	
	1127	"	180	237	32	
	1142	"	178	224	26	
	1155	"	169	240	42	
	1160	"	190	228	20	
	1172	"	104	296	185	
	1201	"	183	229	25	
	1220	"	195	232	18	
	1232	"	186	252	35	
	1367	"	199	249	25	

* PARTS REJECTED AS "OUT-OF-SPEC" DURING GO/NO-GO TEST, BUT FOUND TO BE WITHIN SPEC DURING CAREFULLY CONTROLLED BENCH TEST. THESE MARGINAL PARTS WERE FOUND TO BE HIGHLY SENSITIVE TO TEMPERATURE. WARMING BY FINGERS (SUCH AS COULD OCCUR DURING INSERTION INTO TEST FIXTURE) COULD CAUSE PART TO FAIL 300 mv ROOM TEMPERATURE SPEC.

3.2 HISTOGRAM COMPARISONS

The results of the 1967 and 1975 Parameter Drift measurements have been plotted on common scales in Figures 3-3 through 3-16 for visual evaluation of storage induced changes. Each plot presents results from a single parameter test on a single Logic Function family of parts. For example, Figure 3-3 shows the $I_{IN}(3)$ measurements for the Twin Buffer devices. The remaining plots follow in the order defined in Table 3-I. Each figure contains the following information:

a) a schematic showing the test conditions used to measure the parameter. The physical elements (specific resistors and transistors) being measured have been circled on the schematic.

b) the 1967 measured performance distribution or histogram (dashed line) plotted on top of the histogram of 1975 test results (solid line). Appearing above this figure is a table of mean values and standard deviations associated with the 1967 and 1975 test results. The Delta values apply to item (c) described below.

c) a histogram of the 1967-1975 changes in individual part performance. Parts that have drifted closer to specification limits (degraded) appear along the negative axis.

Each histogram comparison has been technically evaluated to determine whether the 1967-1975 changes can be attributed to normal measurement differences or whether parameter drift has actually occurred. Each of these leaves its own signature in the histograms. Measurement differences include: (1) a bias, or shift in mean value, due to a small difference in the test set up, and (2) random sampling errors due to the limited precision to which each parameter is measured. The latter will tend to have a normal, or bell-shaped distribution.

When measurement differences are present, the 1975 histogram will have a shape very similar to the 1967 histogram, but may be shifted to the right or left. The 1967-1975 change histogram will show a near-normal distribution about a mean value equal to the bias between the two test measurements.

Where significant parameter drift has occurred, the 1975 histogram will tend to be skewed, or stretched closer to the specification limit than the 1967 histogram. The mean value also may have shifted toward the spec limit although there may be little change in the above average parts. Since the below average parts tend to drift more rapidly than the better performers, the 1967-1975 change histogram will not be bell-shaped, but will show a pronounced skewness in the negative (degraded performance) direction.

The criteria discussed above have been used to evaluate the histogram comparisons. These evaluations appear in Tables 3-X through 3-XVI. These seven tables cover the seven families of logic function devices, starting with the Twin Buffer, Table 3-X. The remaining six tables immediately preceed the histogram plots for the other six logic function devices.

The histogram plots confirm the assessments already made from the Summary Tables (Tables 3-II through 3-VIII). In fact, evaluation

3.2 HISTOGRAM COMPARISONS (Continued)

of the histograms sometimes shows that drift has occurred in parameters that did not exceed the conservative 99% confidence criterion used in the statistical tests. The I_{OUT} (Resistance) measurements still show no clear evidence of drift. The most sensitive transistor parameter, V_{OUT}, shows drift on each logic function device, with significant drift occurring on the Double Gate, Register, and Expander. These are the three devices that showed drift at the 99% confidence level. In all cases, drift is most pronounced in the below-average parts. The less sensitive transistor performance parameters, I_{IN}, and V_{OL}, suggest that drift has occurred on some of the devices, but the magnitude is small and difficult to separate from the measurement differences. The best indications of drift on these parameters appears in the below average parts from the Double Gate, Register, and Expander families.

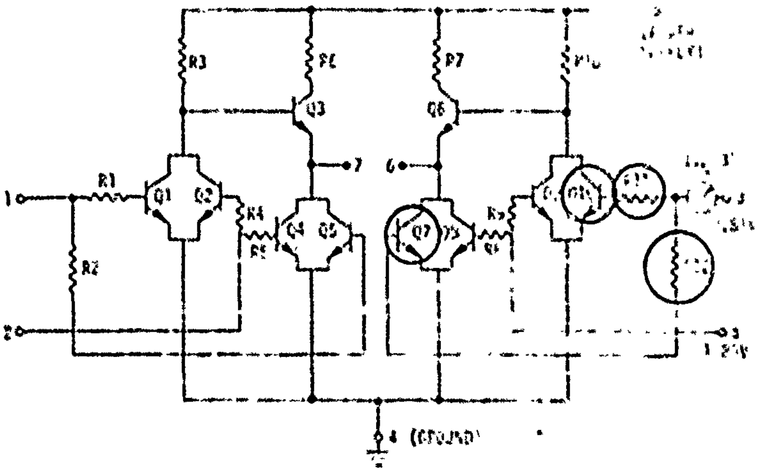
The I_L, I_{RT}, and I_{CEX} measurements made in 1967 were not carried out to the nanoamp precision required to quantitatively evaluate leakage current drift. However, they were sufficiently accurate to state with confidence that significant drift in leakage characteristics did not occur. Because of their greater precision, the 1975 tests showed the leakage rates actually to be lower in some devices than the 1967 measurements indicated.

TABLE 3-X. EVALUATION OF HISTOGRAM COMPARISONS FOR THE TWIN BUFFER

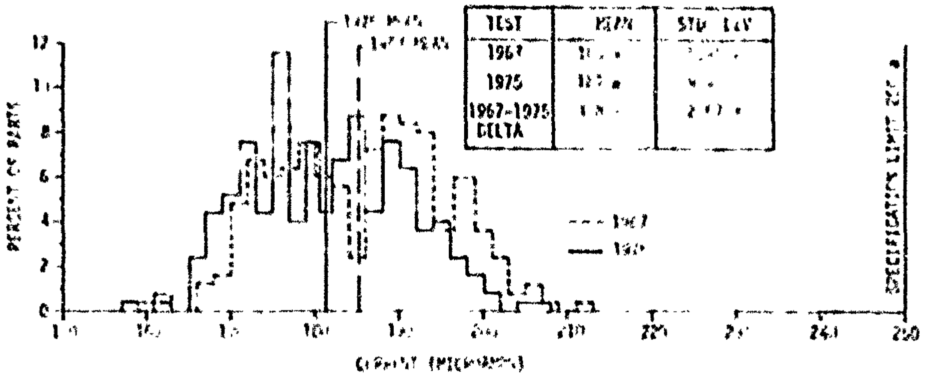
LEGEND	
✓	SLIGHT TREND
✓✓	MODERATE TREND
✓✓✓	PRONOUNCED TREND

PARAMETER (FIGURE NO.)	* TRENDS OBSERVED IN HISTOGRAM COMPARISONS						TECHNICAL ASSESSMENT
	TYPICAL MEASUREMENT DIFFERENCES			TYPICAL PARAMETER DRIFT			
	1961 - 1975 HISTOGRAPHS SIMILAR IN SHAPE	SMALL SHIFT IN MEAN ATTRIBUTABLE TO MEASUREMENT DIFFERENCES	NEAR NORMAL DISTRIBUTION OF 1967-1975 CHANGES	1975 HISTOGRAM SHIFTED AND SKEWED TOWARD SPEC LIMIT	SHIFT IN 1975 MEAN TOWARD DEGRADED PERFORMANCE	DISTRIBUTION OF 1967-1975 CHANGES SKEWED TOWARD DEGRADATION	
$I_{IN}(3)$ (3-3)	✓✓	✓✓	✓				NO MEASURABLE DRIFT
$I_{OUT}(7)$ (3-4)	✓✓	✓✓	✓				NO MEASURABLE DRIFT
$V_{OUT}(7-1)$ (3-5)				✓✓	✓✓	✓✓	MODERATE DRIFT
$V_{OL}(7-1)$ (3-6)	✓✓✓	✓	✓✓✓				NO MEASURABLE DRIFT
$I_{RT}(1-2)$ (3-7)	✓	✓	✓				NO SIGNIFICANT DRIFT
$I_{RT}(3-5)$ (3-8)	✓	✓	✓				NO SIGNIFICANT DRIFT
$I_L(8)$ (3-9)	✓	✓	✓				NO SIGNIFICANT DRIFT

*NOTE: CHECKS APPEARING IN FIRST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO NORMAL MEASUREMENT ERRORS; CHECKS IN LAST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO PARAMETER DRIFT



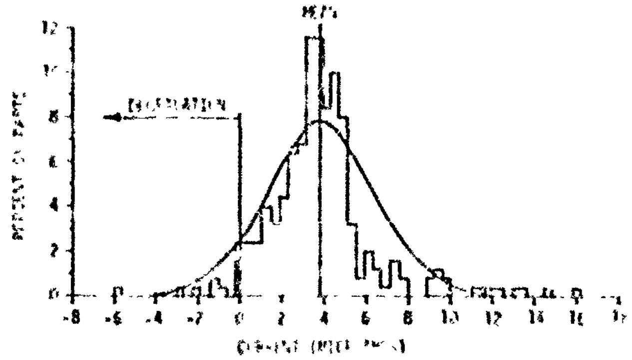
a. SCHEMATIC FOR I_{IN}( ) TEST (GII + [illegible] RESISTANCE + [illegible] BASE [illegible] CHECK AT SATURATION VOLTAGE)



NO. OF PARTS REPRESENTED BY HISTOGRAM [illegible]

TEST	MEAN	STD DEV
1967	[illegible]	[illegible]
1975	[illegible]	[illegible]
1967-1975 DELTA	[illegible]	[illegible]

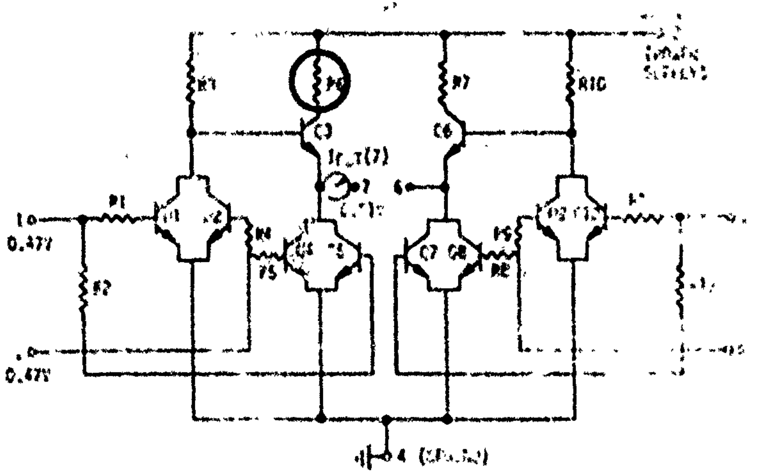
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



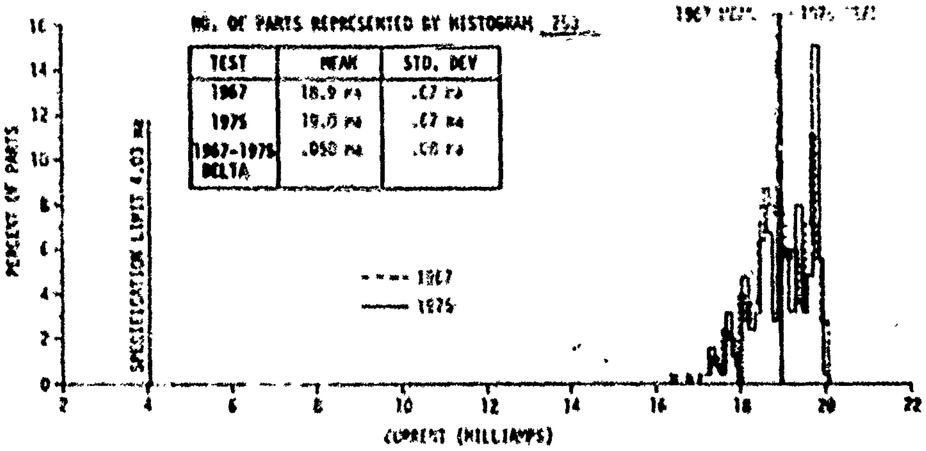
c. 1967 - 1975 CHANGE IN I_{IN}(2)

FIGURE 3-2. HISTOGRAM COMPARISON OF I_{IN}(2)

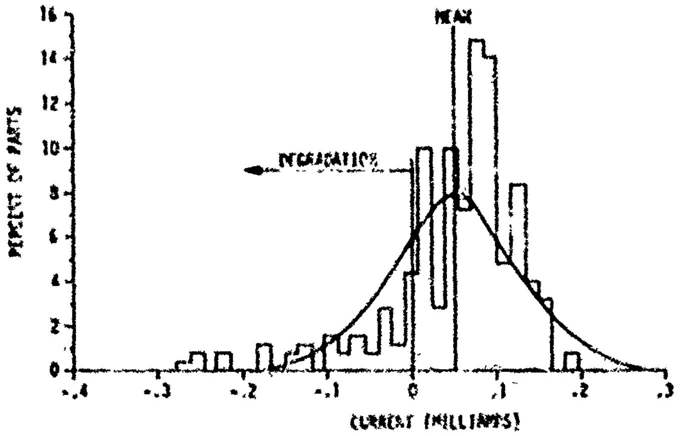
- T [illegible] BUFFER -



a. SCHEMATIC FOR $I_{OUT}(7)$ TEST (R_6 RESISTANCE CHECK)



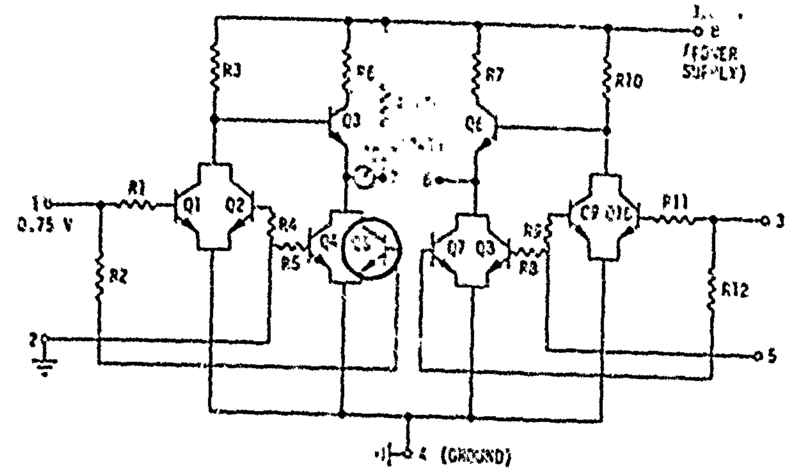
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



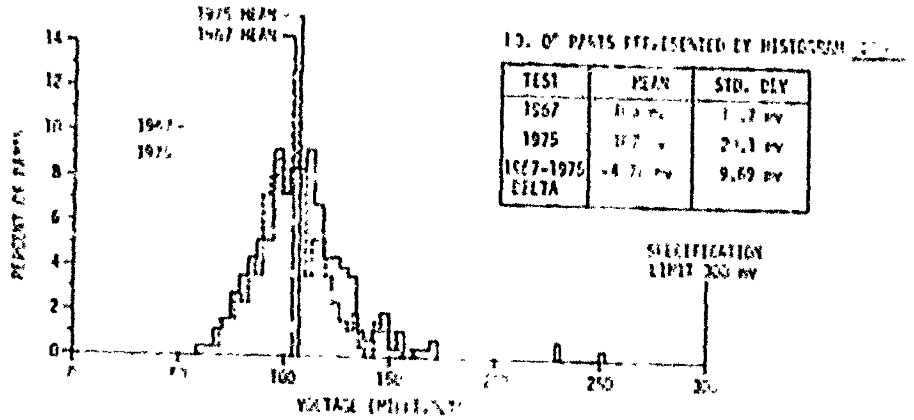
c. 1967-1975 CHANGE IN $I_{OUT}(7)$

FIGURE 3-4 HISTOGRAM COMPARISON OF $I_{OUT}(7)$

- TWIN BUFFER -



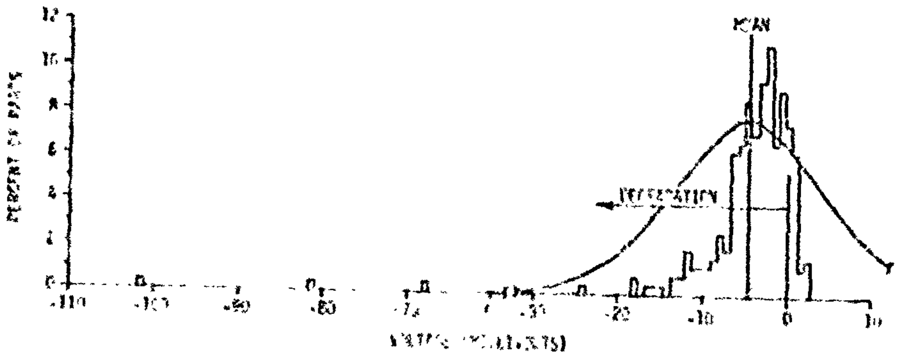
a. SCHEMATIC FOR V_{OUT}(7-11) TEST (C5 VOLTAGE DROP AT MINIMUM "ON" CONDITION)



NO. OF PARTS REPRESENTED BY HISTOGRAM [illegible]

TEST	MEAN	STD. DEV
1967	[illegible]	[illegible]
1975	[illegible]	21.1 mV
1967-1975 DELTA	-4.7 mV	9.69 mV

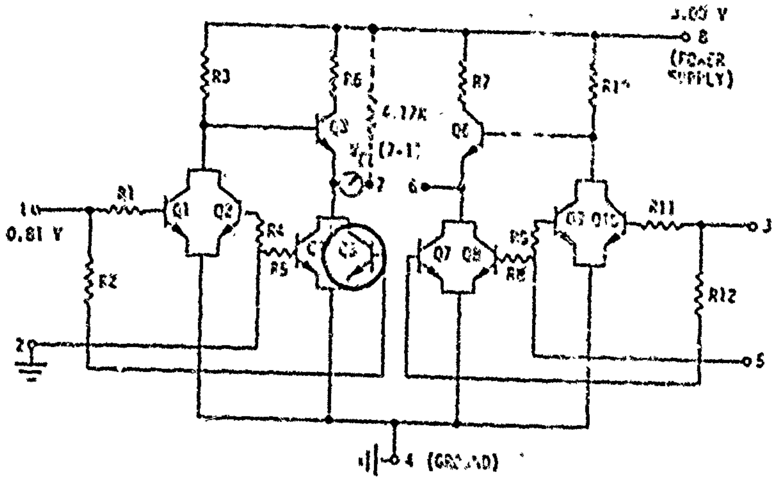
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



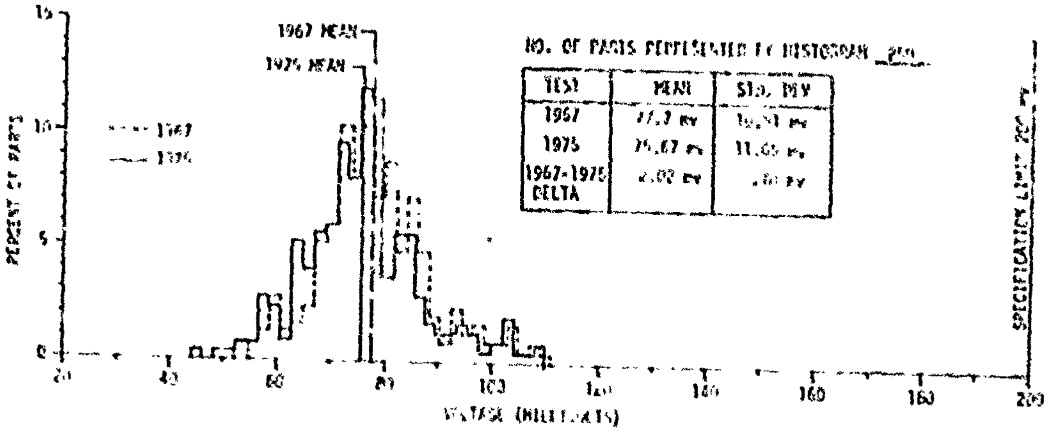
c. 1967 - 1975 CHANGE IN V_{OUT}(7-11)

FIGURE 3-5 HISTOGRAM COMPARISON OF V_{OUT}(7-11)

- TWIN BUFFER -



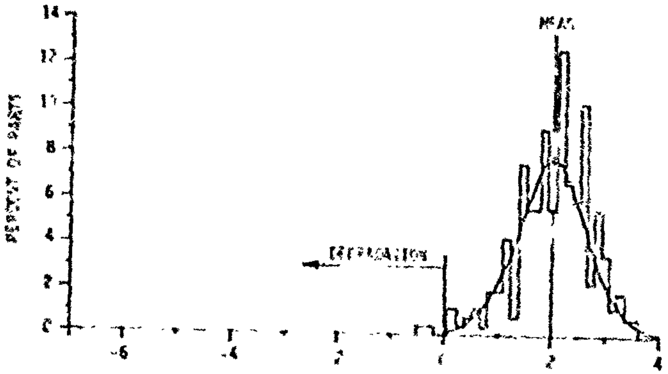
a. SCHEMATIC FOR V_{OL} (7-1) TEST (C5 VOLTAGE DROP AT SATURATION)



NO. OF PARTS REPRESENTED BY HISTOGRAM [illegible]

TEST	MEAN	STD. DEV
1967	77.7 mv	10.[illegible] mv
1975	75.67 mv	11.[illegible] mv
1967-1975 DELTA	2.02 mv	.[illegible] mv

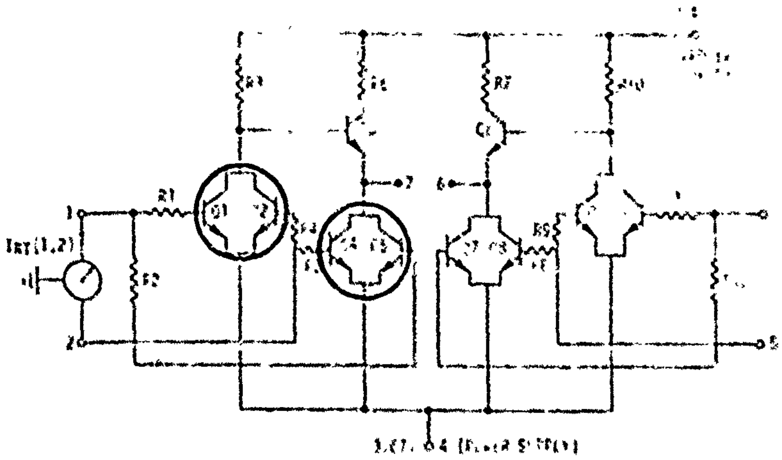
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



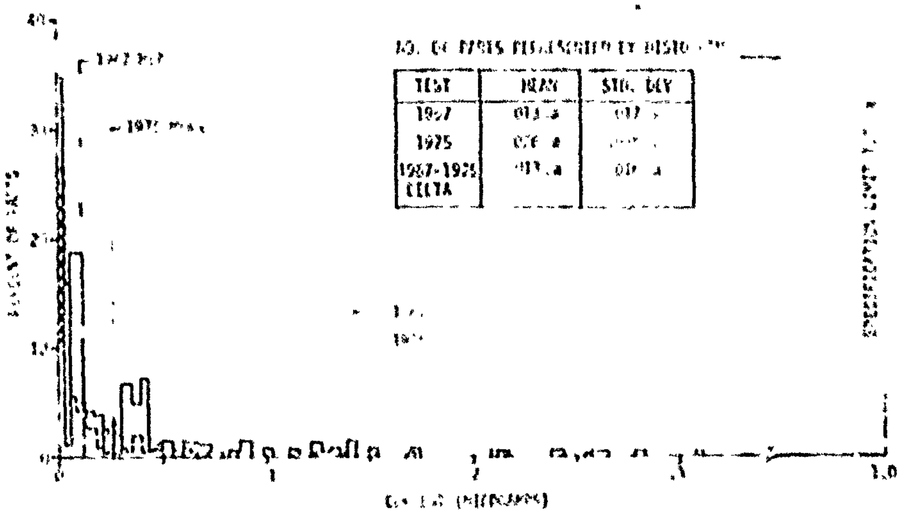
c. 1967 - 1975 CHANGE IN V_{OL} (7-1)

FIGURE 3-8 HISTOGRAM COMPARISON OF V_{OL} (7-1)

-TWIN BUFFER -

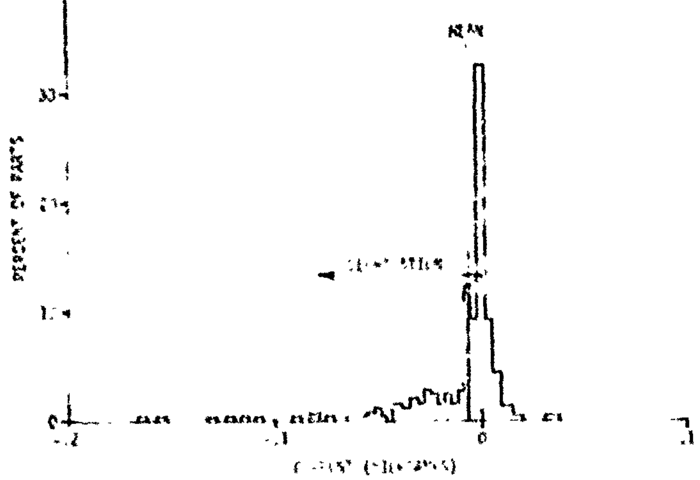


a. SCHEMATIC FOR $I_{RT}(1,2)$ TEST (Q1+Q2+Q4+Q5 BASE EMITTER JUNCTION LEAKAGE CURRENT)



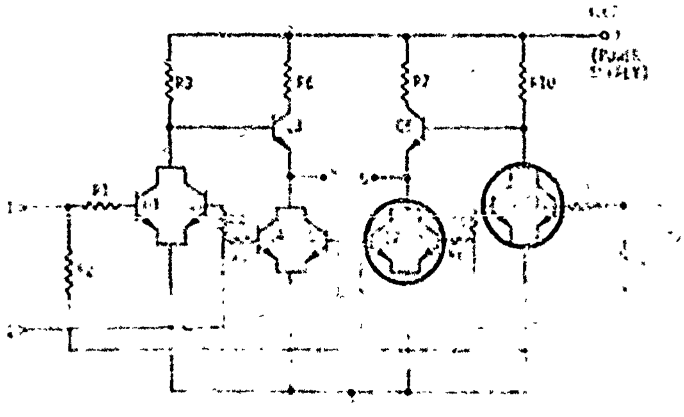
TEST	MEAN	STD. DEV
1967	[illegible]	[illegible]
1975	[illegible]	[illegible]
1967-1975 DELTA	[illegible]	[illegible]

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

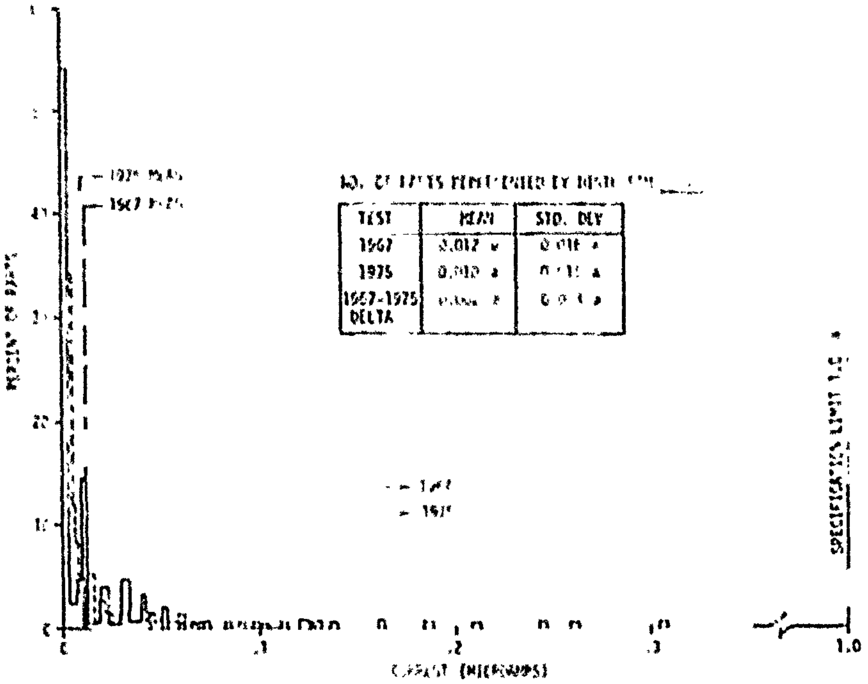


c 1967-1975 CHANGE IN $I_{RT}(1,2)$

FIGURE 3-7 HISTOGRAM COMPARISON OF $I_{RT}(1,2)$
TWIN BUFFER

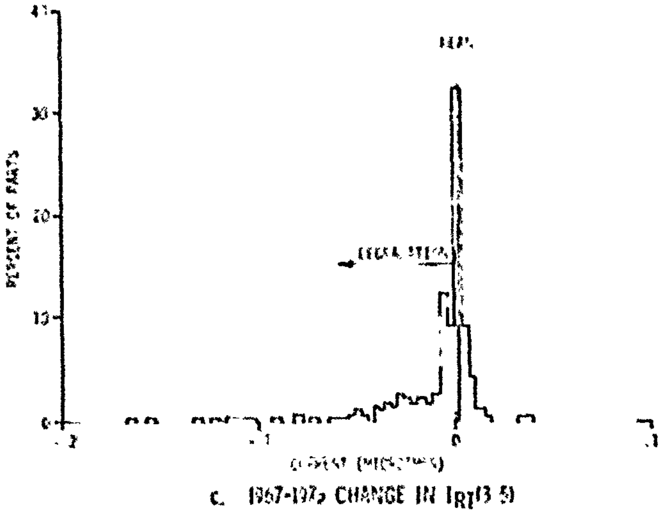


a SCHEMATIC FOR I_{RT}(2,5) TEST (Q7+Q8+Q9+Q10 BASE EMITTER JUNCTION LEAKAGE CURRENT)



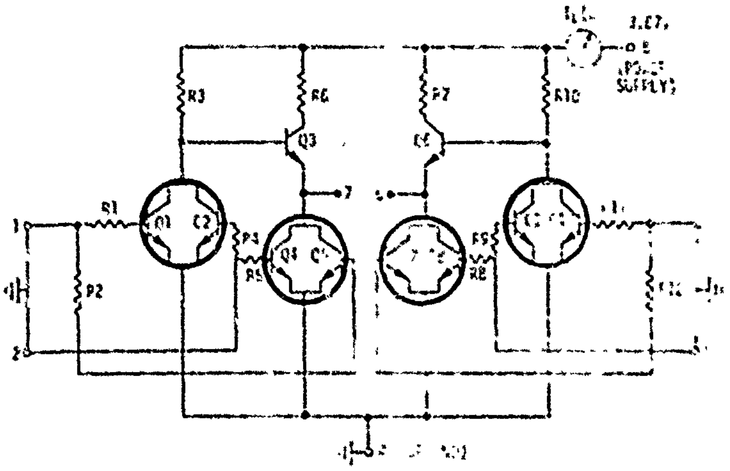
TEST	MEAN	STD. DEV
1967	0.012 [illegible]	[illegible]
1975	0.010 [illegible]	[illegible]
1967-1975 DELTA	[illegible]	[illegible]

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

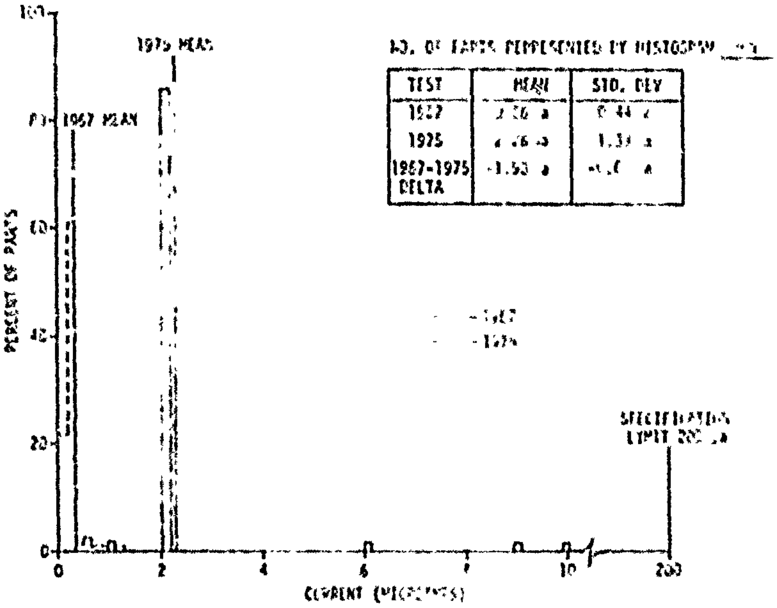


c. 1967-1975 CHANGE IN I_{RT}(3-5)

FIGURE 3-8 HISTOGRAM COMPARISON OF I_{RT}(3-5) TWIN BUFFER

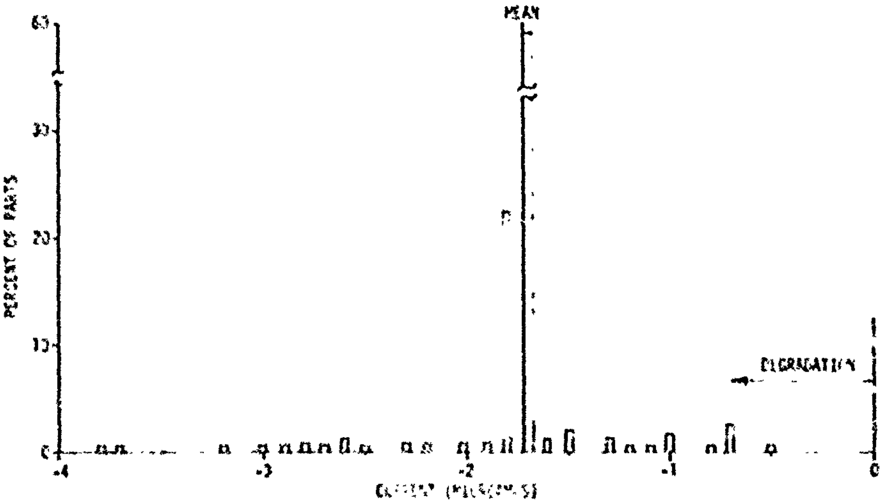


a. SCHEMATIC FOR $I_L(S)$ TEST (Q1+Q2+Q4+Q5+Q7+Q8+Q9+Q10 LEAKAGE CURRENT



TEST	MEAN	STD. DEV
1967	[illegible]	0.44 [illegible]
1975	[illegible]	1.3[illegible]
1967-1975 DELTA	-1.53 [illegible]	[illegible]

b. DISTRIBUTION OF PARTS: 1975 VS. 1967 TEST



c. 1967-1975 CHANGE IN $I_L(S)$

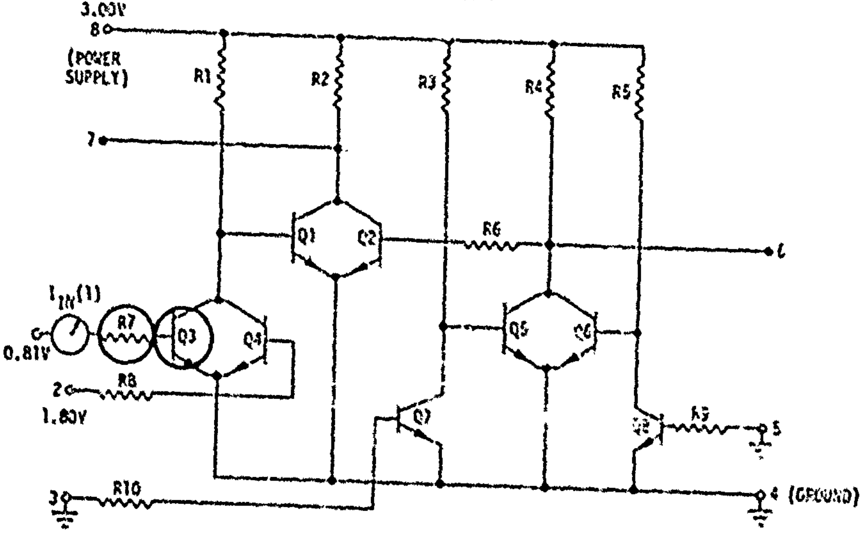
FIGURE 3-9. HISTOGRAM COMPARISON OF $I_L(S)$ TWIN BUFFER

TABLE 3-XI. EVALUATION OF HISTOGRAM COMPARISONS FOR THE ADDER

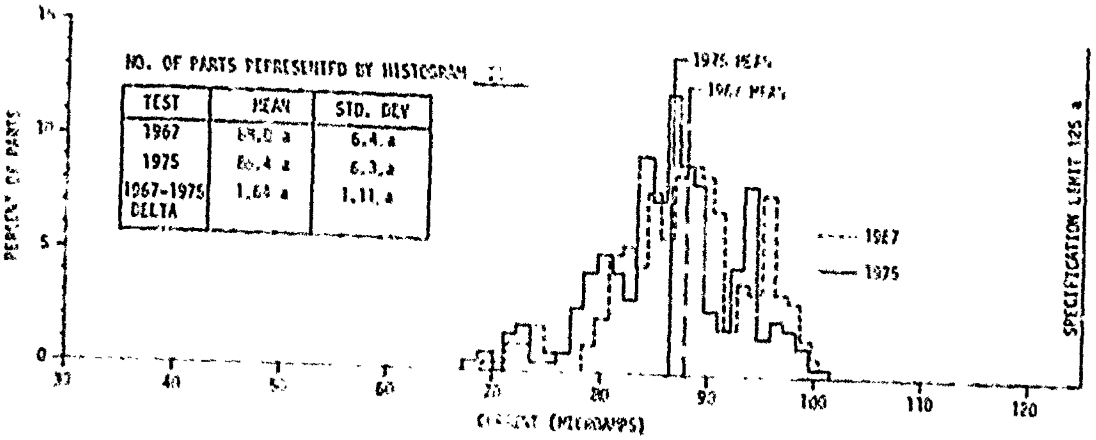
LEGEND	
✓	SLIGHT TREND
✓✓	MODERATE TREND
✓✓✓	PRONOUNCED TREND

PARAMETER (FIGURE NO.)	* TRENDS OBSERVED IN HISTOGRAM COMPARISONS: TYPICAL MEASUREMENT DIFFERENCES: 1967 - 1975 HISTOGRAPHS SIMILAR IN SHAPE	TYPICAL MEASUREMENT DIFFERENCES: SMALL SHIFT IN MEAN ATTRIBUTABLE TO MEASUREMENT DIFFERENCES	TYPICAL MEASUREMENT DIFFERENCES: NEAR NORMAL DISTRIBUTION OF 1967-1975 CHANGES	TYPICAL PARAMETER DRIFT: 1975 HISTOGRAM SHIFTED AND SKEWED TOWARD SPEC LIMIT	TYPICAL PARAMETER DRIFT: SHIFT IN 1975 MEAN TOWARD DEGRADED PERFORMANCE	TYPICAL PARAMETER DRIFT: DISTRIBUTION OF 1967-1975 CHANGES SKEWED TOWARD DEGRADATION	TECHNICAL ASSESSMENT
I_{IN}(1) (3-10)	✓✓	✓✓	✓✓				NO MEASURABLE DRIFT
I_{OUT}(6) (3-11)	✓✓✓	✓✓	✓✓				NO MEASURABLE DRIFT
I_{OUT}(7-1) (3-11a)	✓✓✓	✓✓	✓✓				NO MEASURABLE DRIFT
V_{OL}(7-1) (3-12)	✓✓	✓✓✓	✓✓	✓	✓		NO MEASURABLE DRIFT
I_{RT}(1,2,3,5) (3-13)	✓	✓	✓				NO SIGNIFICANT DRIFT
I_L(8) (3-14)	✓	✓	✓				NO SIGNIFICANT DRIFT

*NOTE: CHECKS APPEARING IN FIRST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO NORMAL MEASUREMENT ERRORS; CHECKS IN LAST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO PARAMETER DRIFT

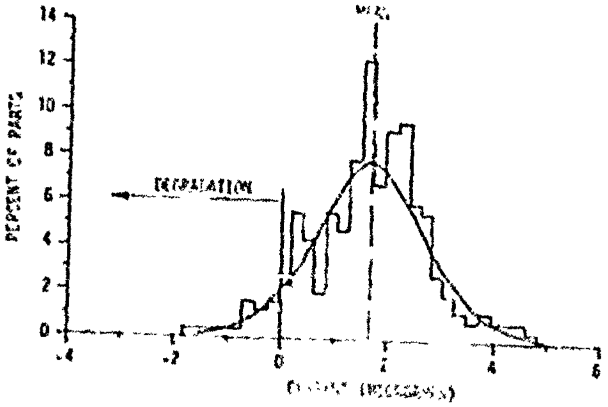


a. SCHEMATIC FOR $I_{IN}(1)$ TEST (R7 RESISTANCE AND Q3 BASE EMITTER CHECK AT SATURATION VOLTAGE)



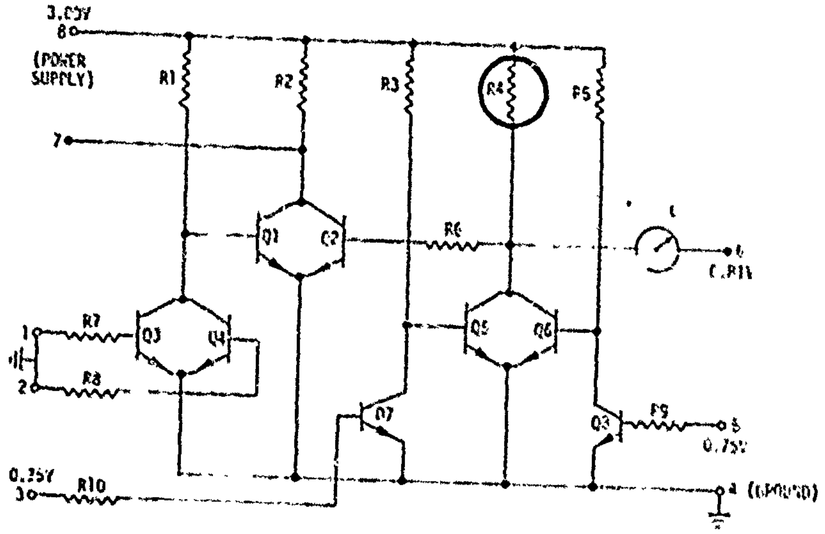
TEST	MEAN	STD. DEV
1967	85.0 a	6.4 a
1975	86.4 a	6.3 a
1967-1975 DELTA	1.64 a	1.11 a

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

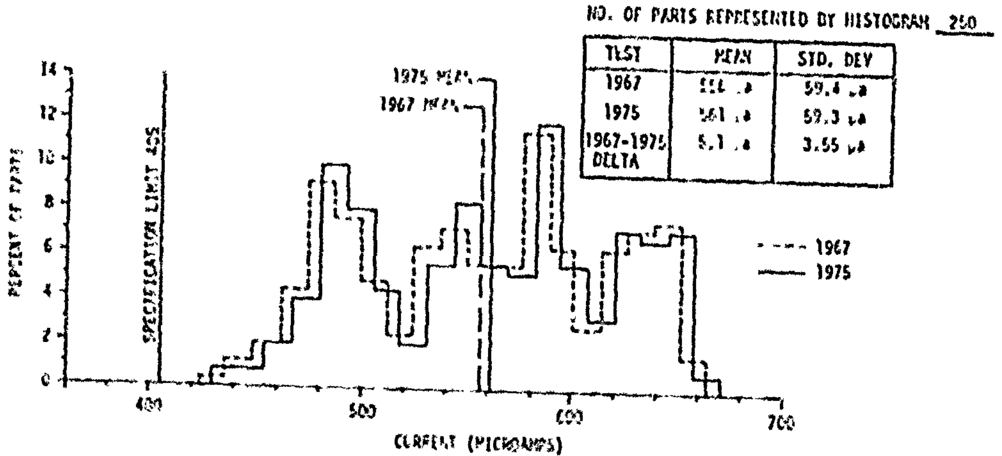


c. 1967 - 1975 CHANGE IN $I_{IN}(1)$

FIGURE 3-12. HISTOGRAM COMPARISON OF $I_{IN}(1)$

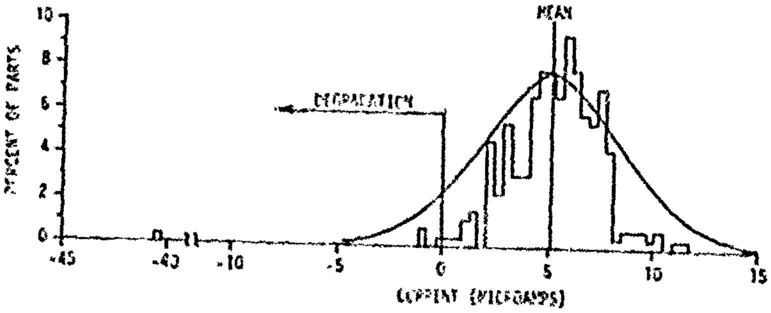


a. SCHEMATIC FOR $I_{OUT(6)}$ TEST (R$_4$ RESISTANCE CHECK)



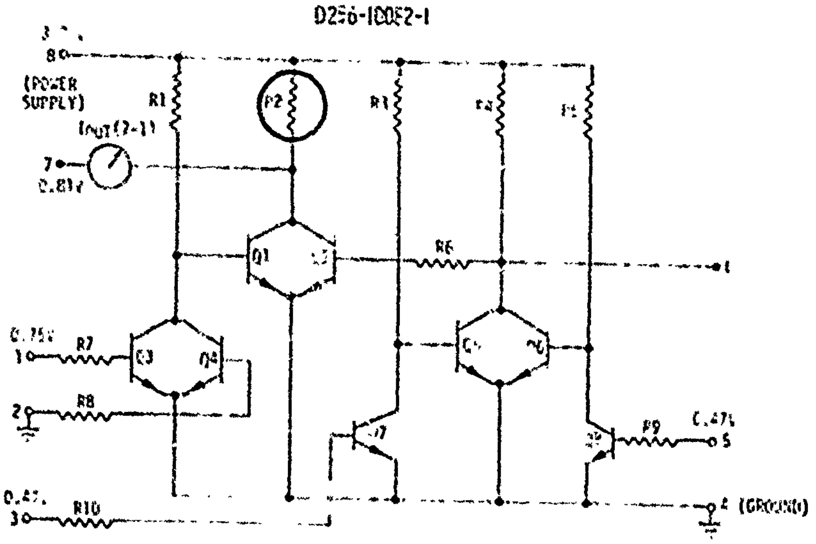
TEST	MEAN	STD. DEV
1967	556 μa	59.4 μa
1975	561 μa	59.3 μa
1967-1975 DELTA	5.1 μa	3.55 μa

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

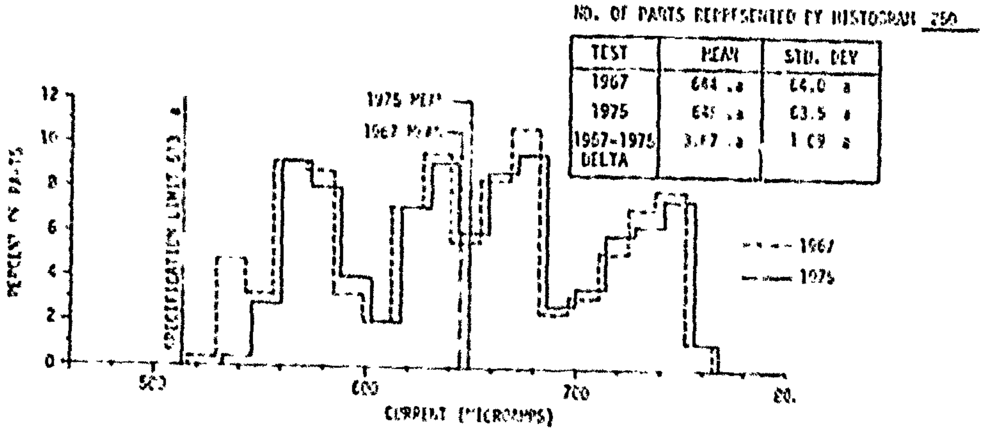


c. 1967-1975 CHANGE IN $I_{OUT(6)}$

FIGURE 3-11. HISTOGRAM COMPARISON OF $I_{OUT(6)}$



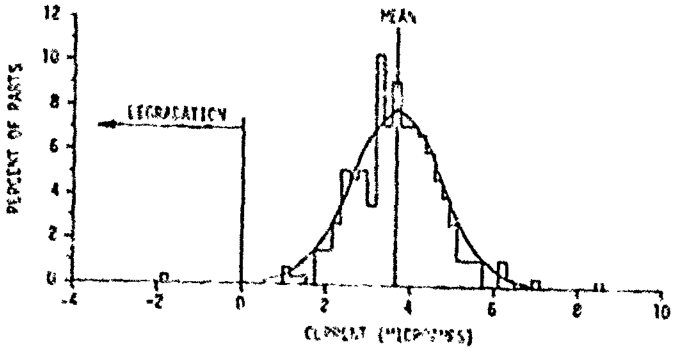
a. SCHEMATIC FOR $I_{OUT}(7\text{-}1)$ TEST (R_2 RESISTANCE CHECK)



NO. OF PARTS REPRESENTED BY HISTOGRAM 250

TEST	MEAN	STD. DEV
1967	644 μa	64.0 μa
1975	648 μa	63.5 μa
1967-1975 DELTA	3.67 μa	1.09 μa

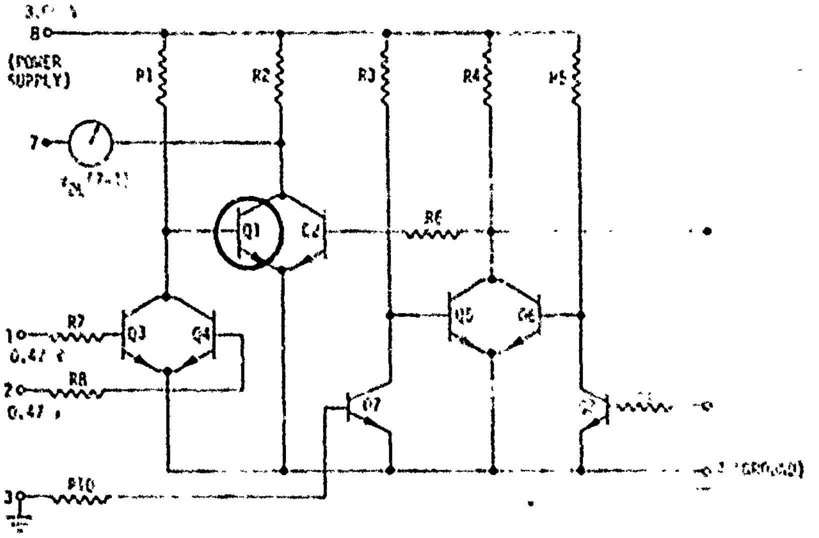
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



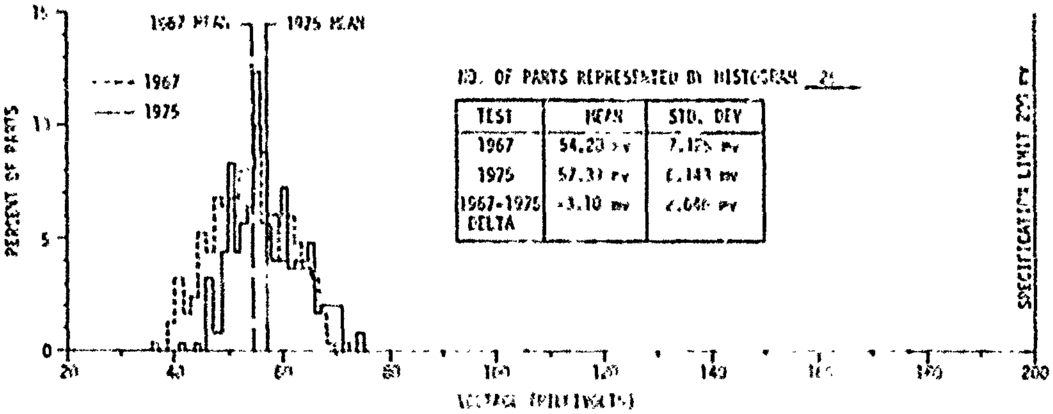
c. 1967-1975 CHANGE IN $I_{OUT}(7\text{-}1)$

FIGURE 3-11a. HISTOGRAM COMPARISON OF $I_{OUT}(7\text{-}1)$

ADDER



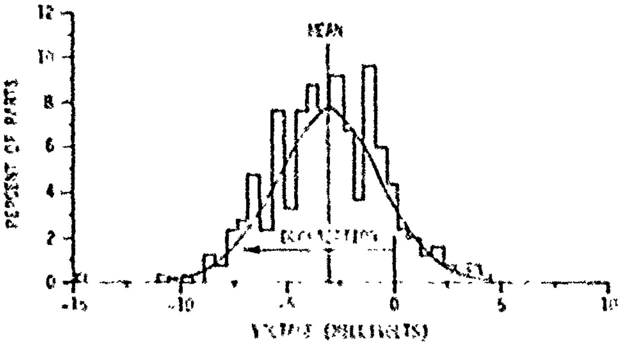
a. SCHEMATIC FOR V_{OL}(7-1) TEST (C1 VOLTAGE DROP AT SATURATION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 2[illegible]

TEST	MEAN	STD. DEV
1967	54.20 mv	7.175 mv
1975	57.30 mv	6.143 mv
1967-1975 DELTA	-3.10 mv	2.646 mv

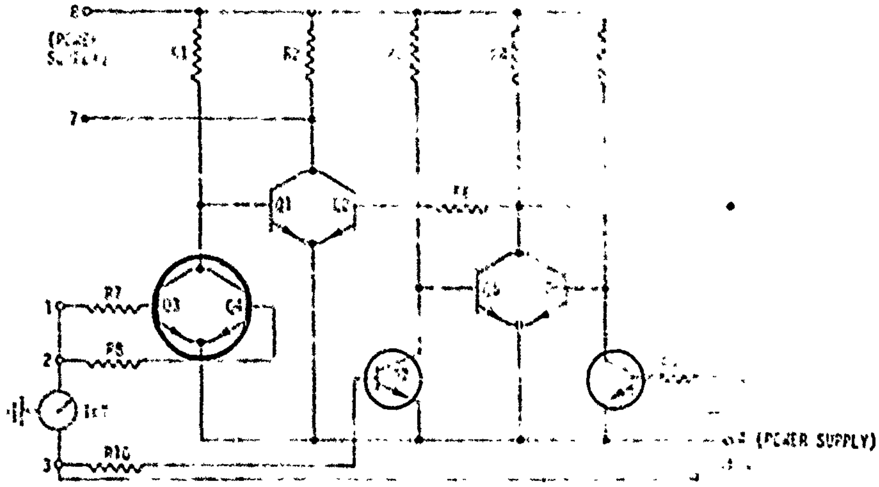
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



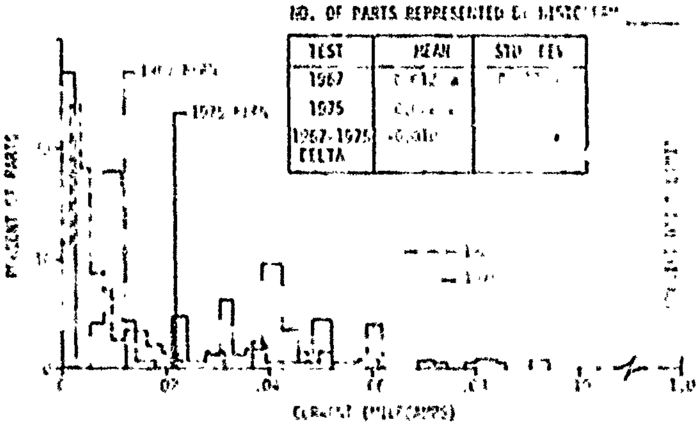
c. 1967 - 1975 CHANGE IN V_{OL}(7-1)

FIGURE 3-12. HISTOGRAM COMPARISON OF V_{OL}(7-1)

- ADDER -



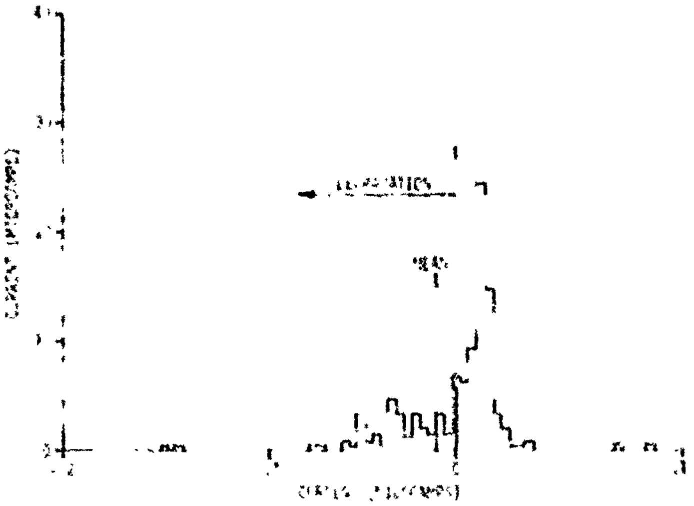
a SCHEMATIC FOR I_{RT} (1, 2, 3-5) TEST (Q3+Q4+Q7+Q8 BASE EMITTER JUNCTION LEAKAGE CURRENT)



NO. OF PARTS REPRESENTED BY HISTOGRAM

TEST	MEAN	STD DEV
1967	[illegible]	[illegible]
1975	[illegible]	
1967-1975 DELTA	[illegible]	

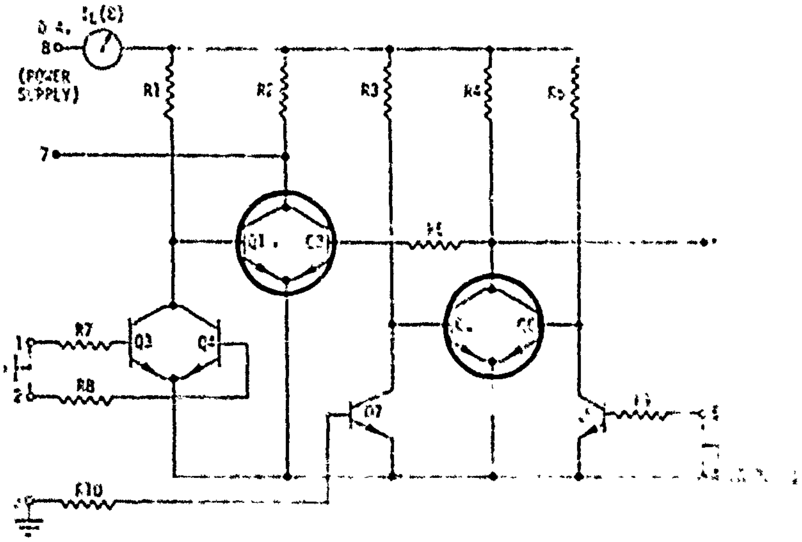
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



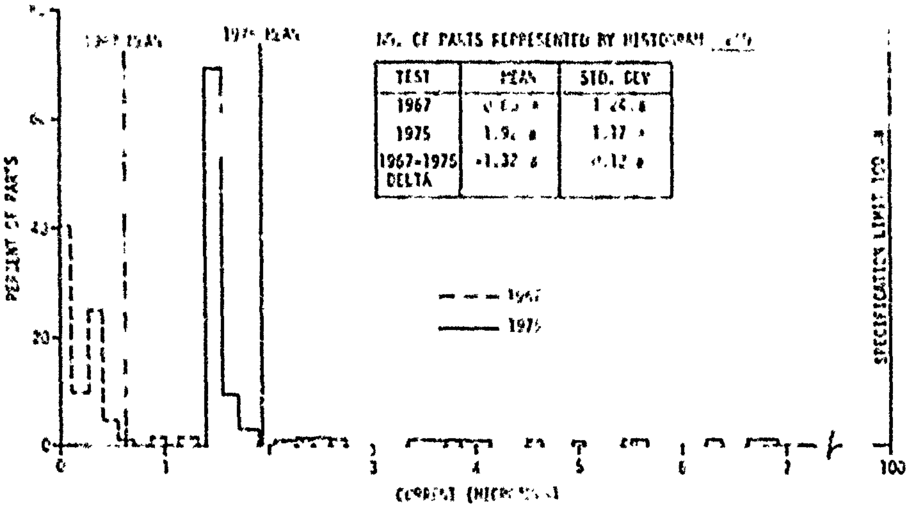
c. 1967-1975 CHANGE IN I_{RT} (1 2,3-5)

FIGURE 3-13. HISTOGRAM COMPARISON OF I_{RT} (1 2,3-5)

ADDER

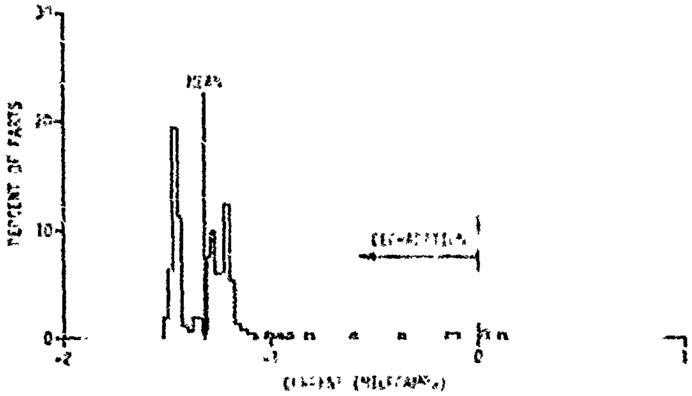


a. SCHEMATIC FOR $I_L(8)$ TEST (Q1+Q2+Q5+Q6 LEAKAGE CURRENT JUST BELOW MAX "OFF" VOLTAGE



TEST	MEAN	STD. DEV
1967	[illegible]	[illegible]
1975	1.9[illegible]	1.17
1967-1975 DELTA	-1.32	[illegible]

b. DISTRIBUTION OF PARTS: 1975 VS. 1967 TEST



c. 1967-1975 CHANGE IN $I_L(8)$

FIGURE 3-14. HISTOGRAM COMPARISON OF $I_L(8)$

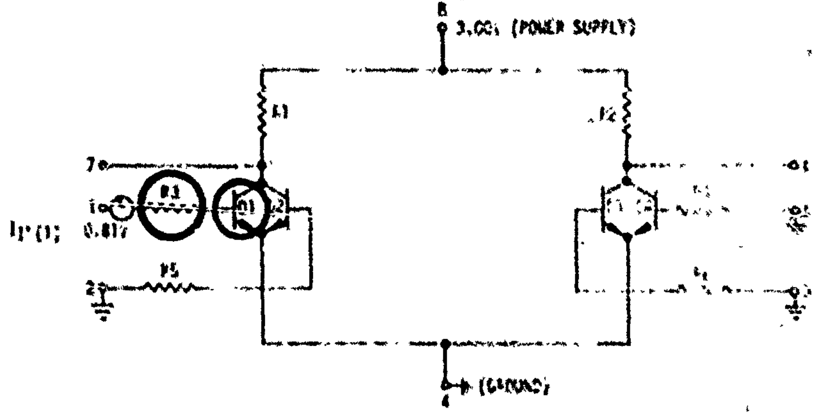
ADDER

TABLE 3-XII. EVALUATION OF HISTOGRAM COMPARISONS FOR THE DOUBLE GATE

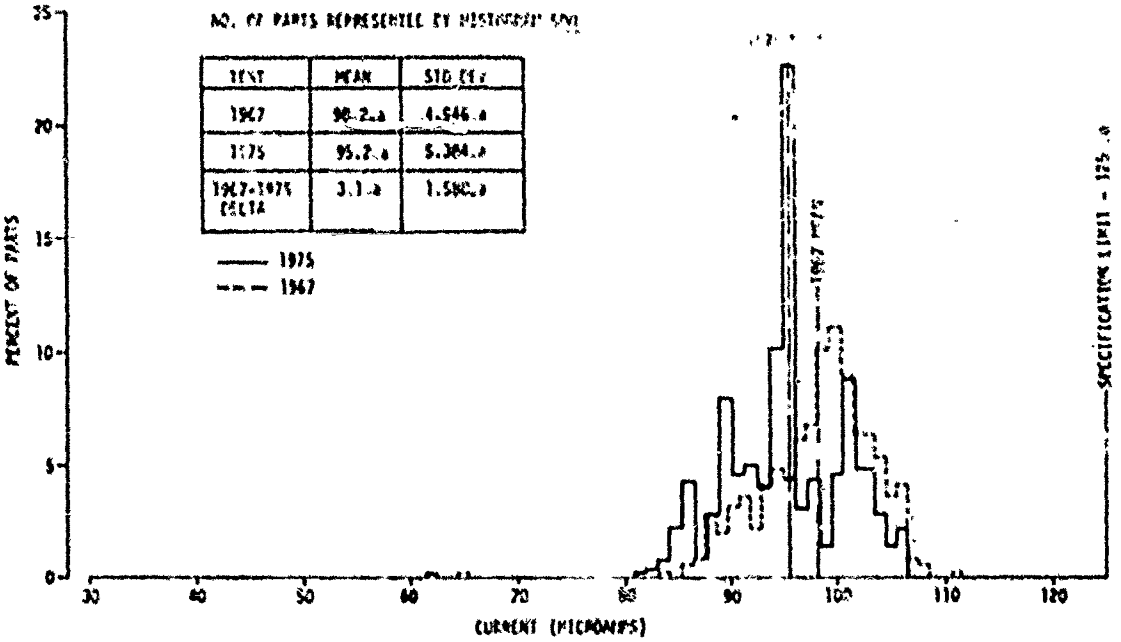
LEGEND	
✓	SLIGHT TREND
✓✓	MODERATE TREND
✓✓✓	PRONOUNCED TREND

	* TRENDS OBSERVED IN HISTOGRAM COMPARISONS						
	TYPICAL MEASUREMENT DIFFERENCES			TYPICAL PARAMETER DRIFT			
PARAMETER (FIGURE NO.)	1967 - 1975 HISTOGRAMS SIMILAR IN SHAPE	SMALL SHIFT IN MEAN ATTRIBUTABLE TO MEASUREMENT DIFFERENCES	NEAR NORMAL DISTRIBUTION OF 1967-1975 CHANGES	1975 HISTOGRAM SHIFTED AND SKEWED TOWARD SPEC LIMIT	SHIFT IN 1975 MEAN TOWARD DEGRADED PERFORMANCE	DISTRIBUTION OF 1967-1975 CHANGES SKEWED TOWARD DEGRADATION	TECHNICAL ASSESSMENT
I_{IN}(1) (3-15)	✓	✓	✓				NO MEASURABLE DRIFT
I_{OUT}(7) (3-16)	✓✓✓	✓	✓✓✓				NO MEASURABLE DRIFT
V_{OUT}(6-1) (3-17)				✓✓✓	✓✓✓	✓✓✓	PRONOUNCED DRIFT
V_{OL}(6-1) (3-18)	✓✓	✓	✓	✓	✓	✓	NO MEASURABLE DRIFT IN +σ PARTS; SLIGHT DRIFT IN -σ PARTS
V_{OL}(7-1) (3-19)	✓✓	✓	✓	✓	✓	✓	NO MEASURABLE DRIFT IN +σ PARTS; SLIGHT DRIFT IN -σ PARTS
I_{RT} (3-20)	✓	✓	✓				NO SIGNIFICANT DRIFT
I_L(8) (3-21)	✓	✓	✓				NO SIGNIFICANT DRIFT

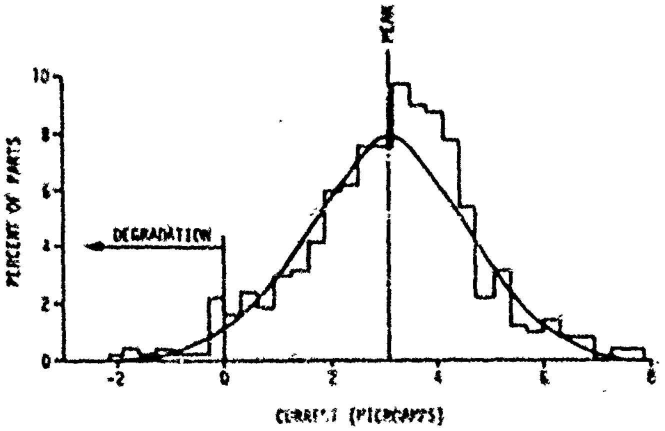
*NOTE: CHECKS APPEARING IN FIRST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO NORMAL MEASUREMENT ERRORS; CHECKS IN LAST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO PARAMETER DRIFT



a. SCHEMATIC FOR I_{IN}(I) TEST (R3 RESISTANCE + Q1 BASE EMITTER-CHECK AT SATURATION VOLTAGE)



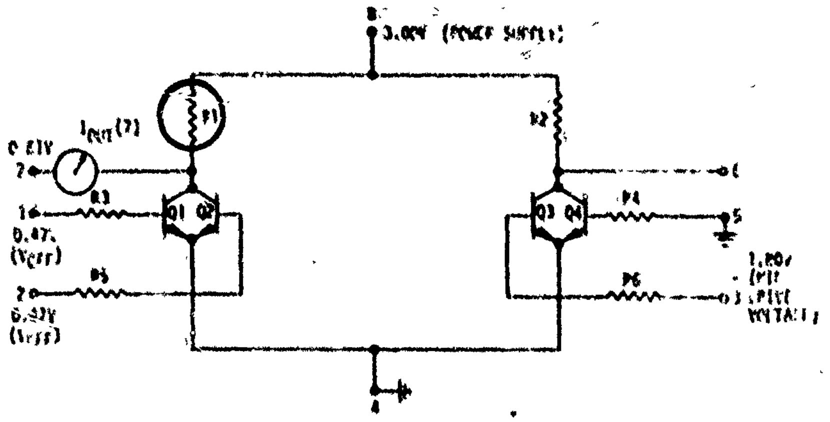
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



c. 1967 - 1975 CHANGE IN I_{IN}(I)

FIGURE 3-15. HISTOGRAM COMPARISON OF I_{IN}(I)

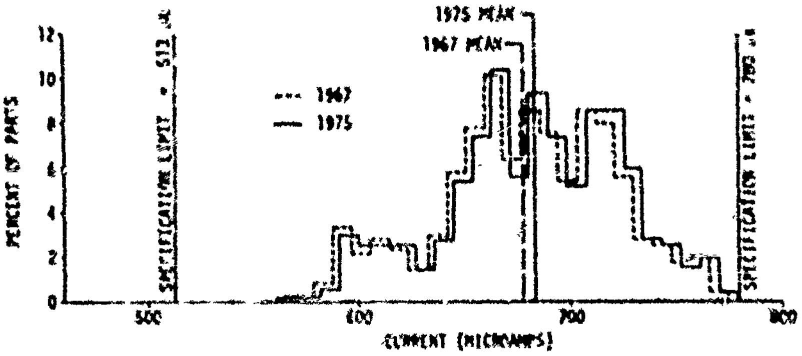
- DOUBLE GATE -



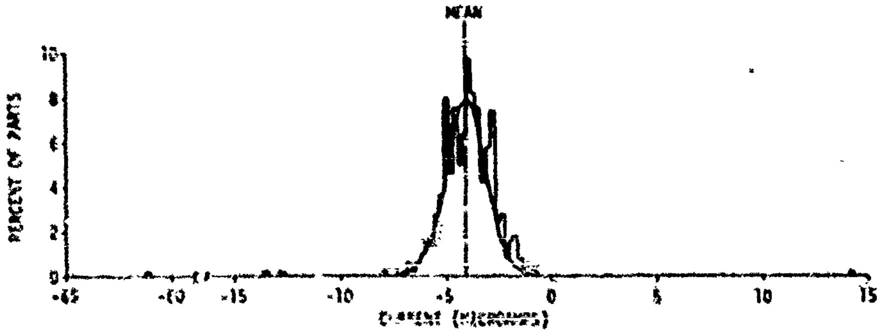
a SCHEMATIC FOR I_{OUT} (7) TEST (R_1 RESISTANCE CHECK)

NO. OF PARTS REPRESENTED BY HISTOGRAM 502

TEST	MEAN	STD DEV.
1967	679 μa	42.5 μa
1975	683 μa	42.5 μa
1967-1975 DELTA	-4 μa	3.0 μa



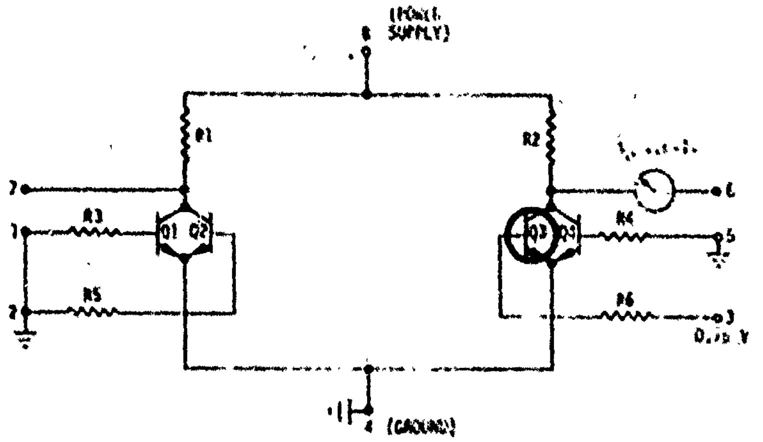
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



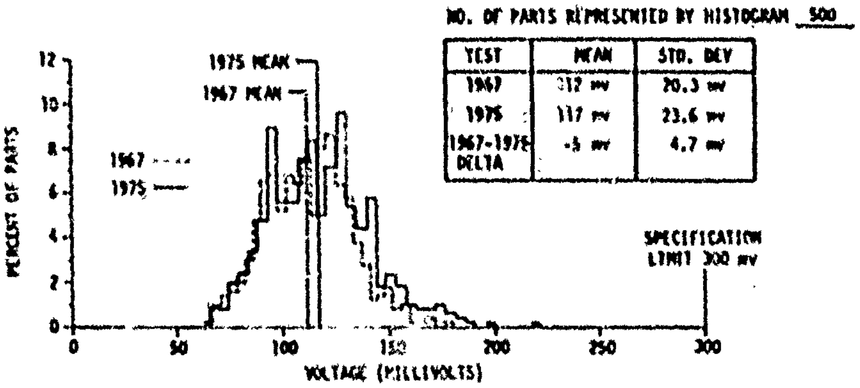
c. 1967-1975 CHANGE IN I_{OUT} (7)

FIGURE 3-36 HISTOGRAM COMPARISON OF I_{OUT} (7)

- DOUBLE GATE -



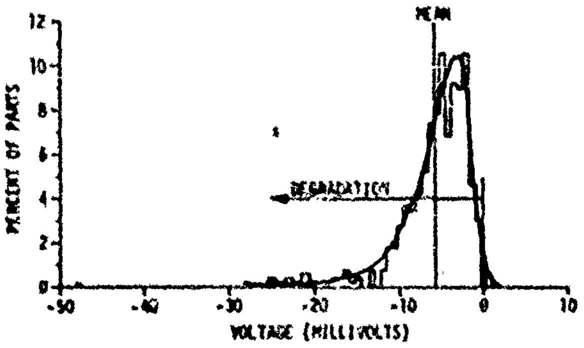
a. SCHEMATIC FOR V_{OUT}(6-1) TEST (Q3 VOLTAGE DROP AT MINIMUM "ON" CONDITION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 500

TEST	MEAN	STD. DEV
1967	112 mv	20.3 mv
1975	117 mv	23.6 mv
1967-1975 DELTA	-5 mv	4.7 mv

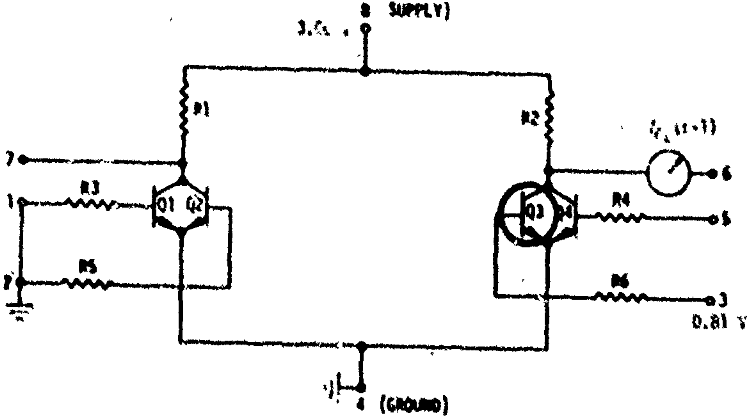
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



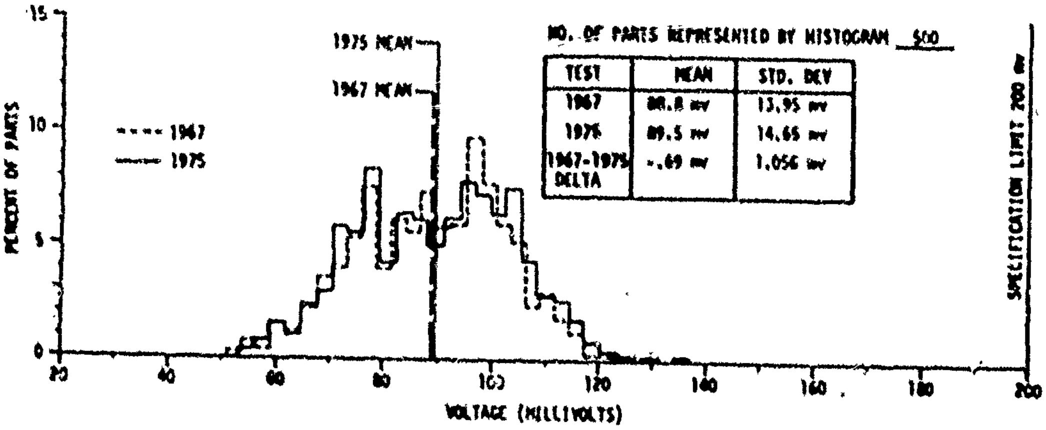
c. 1967 - 1975 CHANGE IN V_{OUT}(6-1)

FIGURE 3-17. HISTOGRAM COMPARISON OF V_{OUT}(6-1)

- DOUBLE GATE -



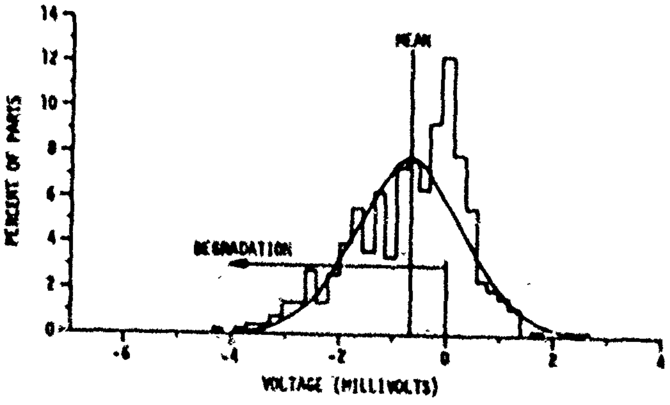
a. SCHEMATIC FOR V_{OL}(6-1) TEST (Q3 VOLTAGE DROP AT SATURATION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 500

TEST	MEAN	STD. DEV
1967	88.8 mv	13.95 mv
1975	89.5 mv	14.65 mv
1967-1975 DELTA	-.69 mv	1.056 mv

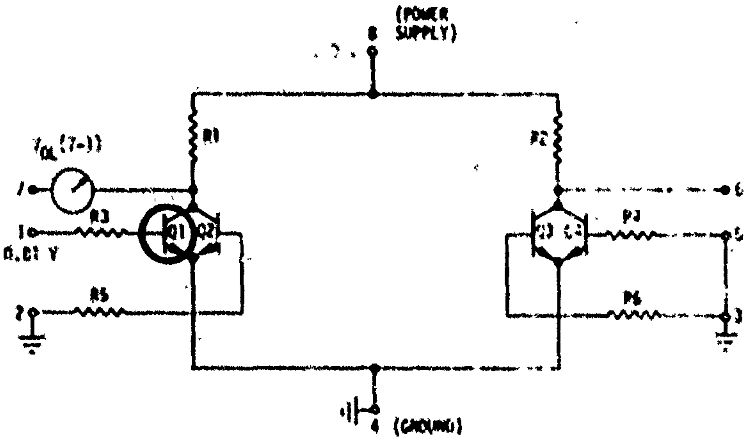
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



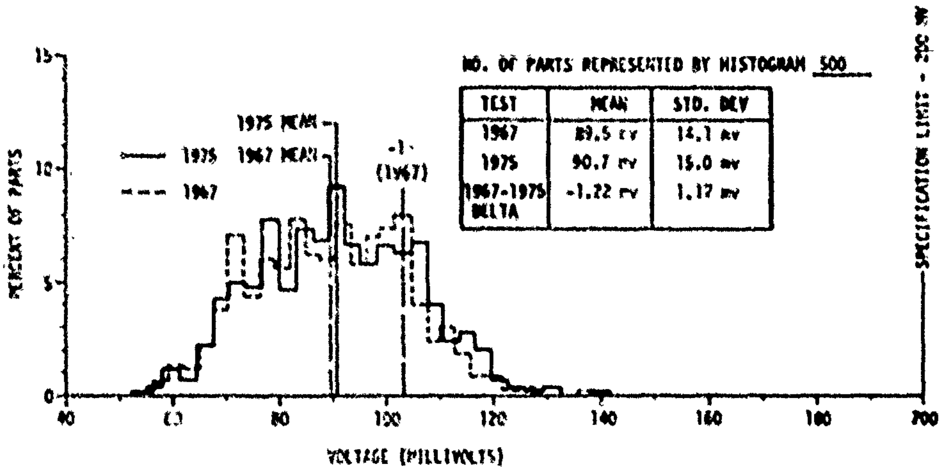
c. 1967 - 1975 CHANGE IN V_{OL}(6-1)

FIGURE 3-38 HISTOGRAM COMPARISON OF V_{OL}(6-1)

- DOUBLE GATE -

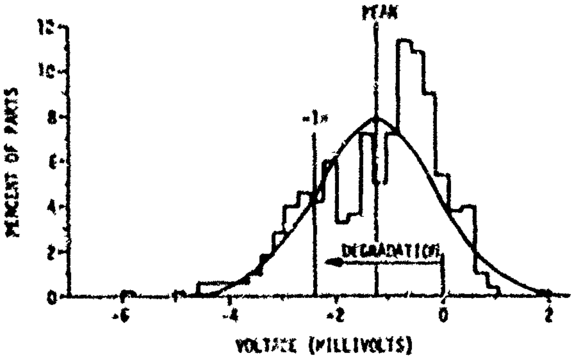


a. SCHEMATIC FOR V_{OL}(7-1) TEST (C1 VOLTAGE DROP AT SATURATION)



TEST	MEAN	STD. DEV
1967	89.5 mv	14.1 mv
1975	90.7 mv	15.0 mv
1967-1975 DELTA	-1.22 mv	1.17 mv

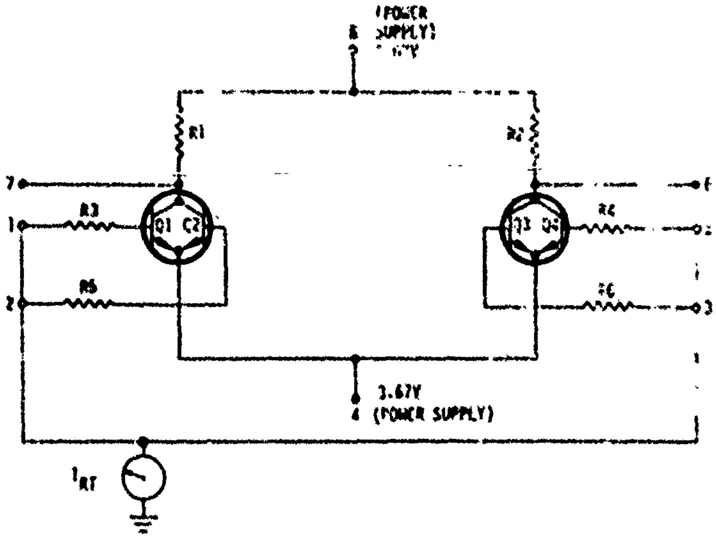
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



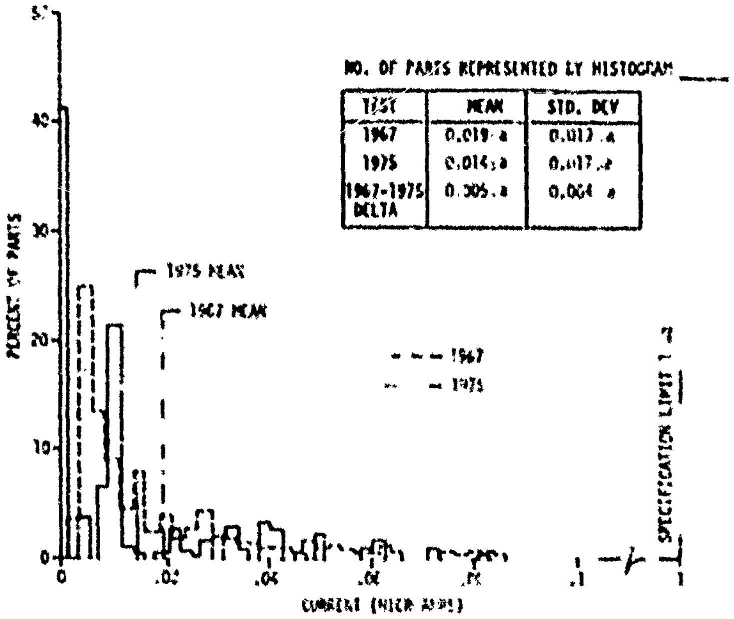
c. 1967 - 1975 CHANGE IN V_{OL}(7-1)

FIGURE 3-19. HISTOGRAM COMPARISON OF V_{OL}(7-1)

- DOUBLE GATE -



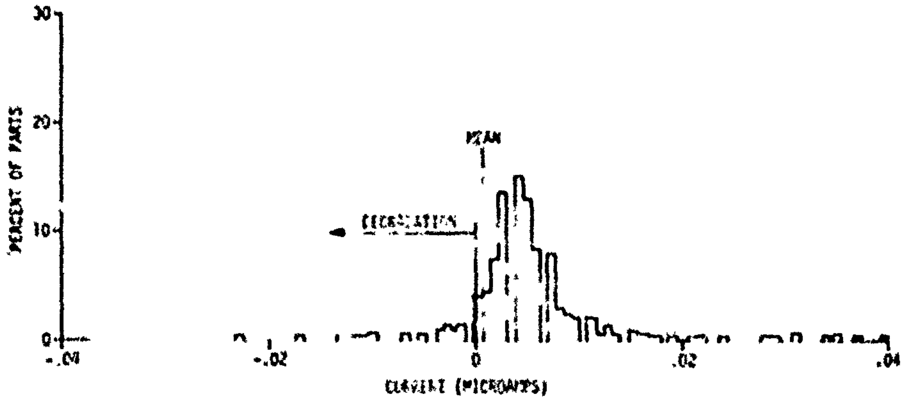
a. SCHEMATIC FOR I_{RT} TEST (Q1+Q2+Q3+Q4 BASE EMITTER JUNCTION LEAKAGE CURRENT



NO. OF PARTS REPRESENTED BY HISTOGRAM

TEST	MEAN	STD. DEV
1967	0.019 μa	0.012 μa
1975	0.014 μa	0.017 μa
1967-1975 DELTA	0.005 μa	0.004 μa

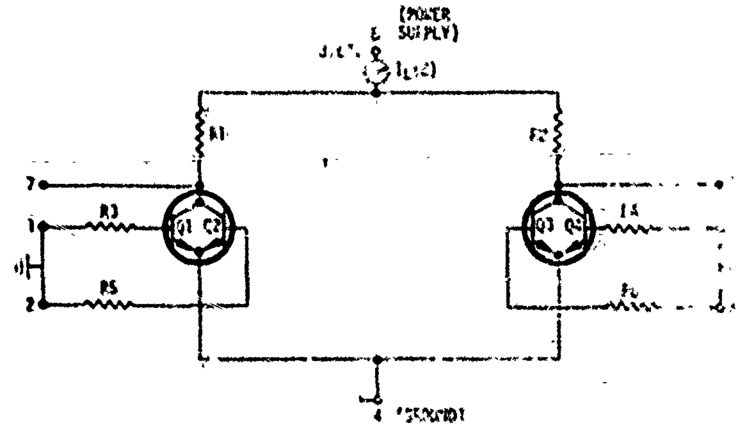
b. DISTRIBUTION OF PARTS: 1975 VS. 1967 TEST



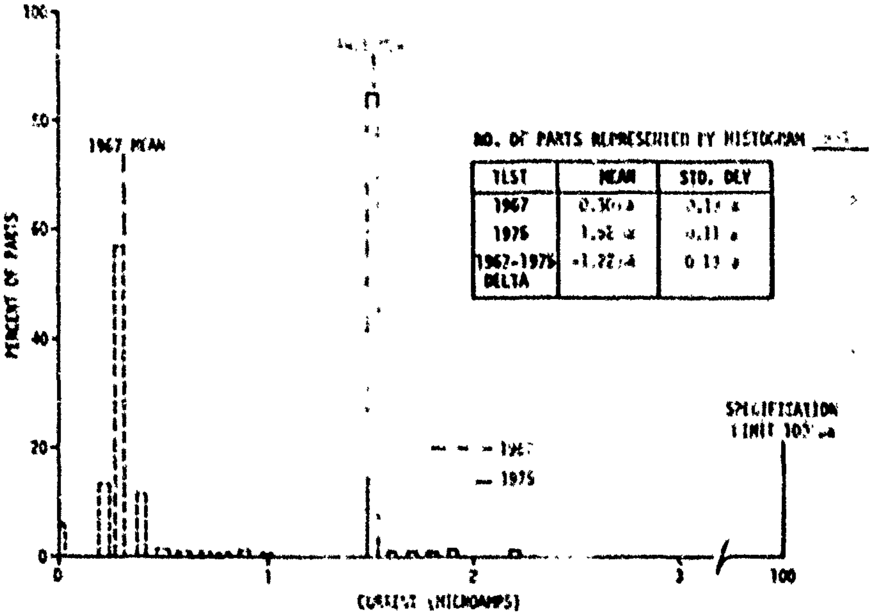
c. 1967-1975 CHANGE IN I_{RT}

FIGURE 3-20. HISTOGRAM COMPARISON OF I_{RT}

DOUBLE GATE



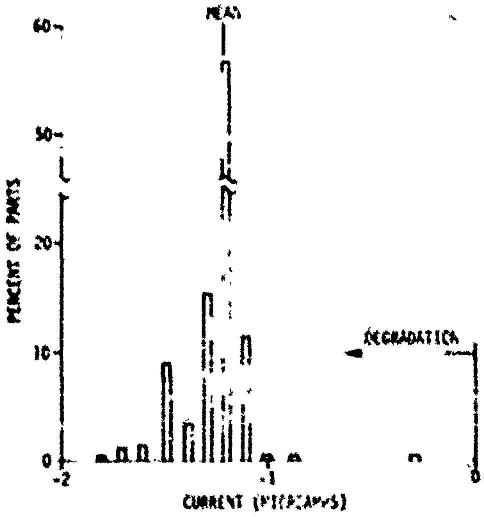
a. SCHEMATIC FOR $I_L(8)$ TEST (Q1+Q2+Q3+Q4 LEAKAGE CURRENT)



NO. OF PARTS REPRESENTED BY HISTOGRAM [illegible]

TEST	MEAN	STD. DEV
1967	0.30 μa	0.1[illegible] μa
1975	1.52 μa	0.11 μa
1967-1975 DELTA	-1.22 μa	0.13 μa

b. DISTRIBUTION OF PARTS, 1975 VS. 1967 TEST



c. 1967-1975 CHANGE IN $I_L(8)$

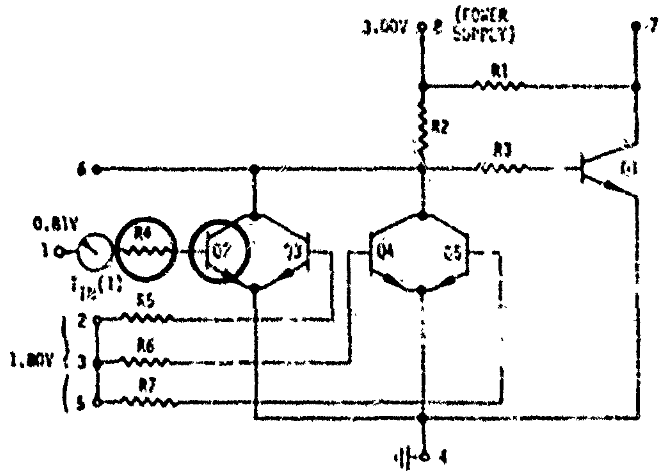
FIGURE 3-21. HISTOGRAM COMPARISON OF $I_L(8)$ DOUBLE GATE

TABLE 3-XIII. EVALUATION OF HISTOGRAM COMPARISONS FOR THE 4-INPUT GATE

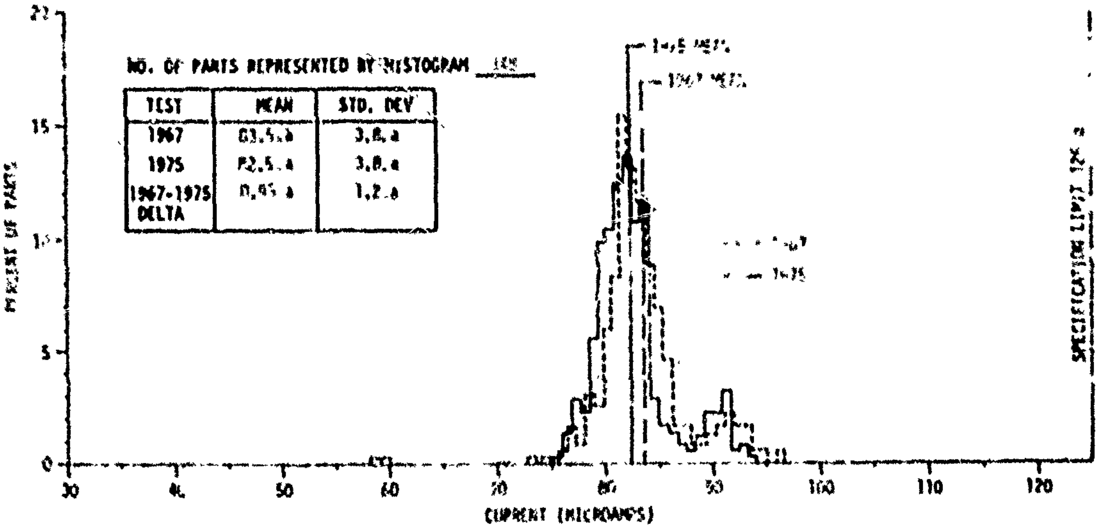
LEGEND	
✓	SLIGHT TREND
✓✓	MODERATE TREND
✓✓✓	PRONOUNCED TREND

PARAMETER (FIGURE NO.)	* TRENDS OBSERVED IN HISTOGRAM COMPARISONS						TECHNICAL ASSESSMENT
	TYPICAL MEASUREMENT DIFFERENCES			TYPICAL PARAMETER DRIFT			
	1967 - 1975 HISTOGRAMS SIMILAR IN SHAPE	SMALL SHIFT IN MEAN ATTRIBUTABLE TO MEASUREMENT DIFFERENCES	NEAR NORMAL DISTRIBUTION OF 1967-1975 CHANGES	1975 HISTOGRAM SHIFTED AND SKEWED TOWARD SPEC LIMIT	SHIFT IN 1975 MEAN TOWARD DEGRADED PERFORMANCE	DISTRIBUTION OF 1967-1975 CHANGES SKEWED TOWARD DEGRADATION	
$I_{IN}(1)$ (3-22)	✓✓	✓✓	✓			✓	NO MEASURABLE DRIFT
$I_{OUT}(7)$ (3-23)	✓✓✓	✓	✓✓✓				NO MEASURABLE DRIFT
$V_{OUT}(6-1)$ (3-24)				✓✓	✓✓	✓✓	MODERATE DRIFT
$V_{OL}(6-1)$ (3-25)	✓✓		✓✓				NO MEASURABLE DRIFT
I_{RT} (3-26)	✓	✓	✓				NO SIGNIFICANT DRIFT
$I_L(8)$ (3-27)	✓	✓	✓				NO SIGNIFICANT DRIFT

*NOTE: CHECKS APPEARING IN FIRST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO NORMAL MEASUREMENT ERRORS; CHECKS IN LAST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO PARAMETER DRIFT

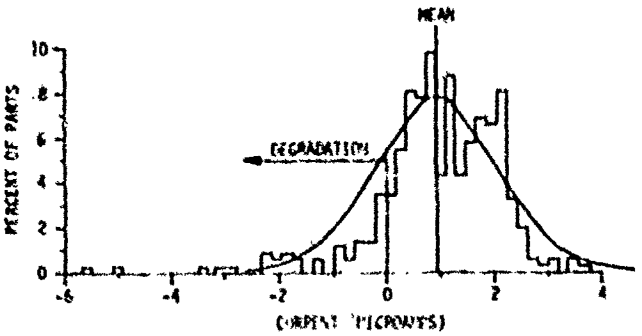


a. SCHEMATIC FOR I_{IN}(I) TEST (R4 RESISTANCE + [illegible])



TEST	MEAN	STD. DEV
1967	83.5 a	3.8 a
1975	82.5 a	3.0 a
1967-1975 DELTA	0.95 a	1.2 a

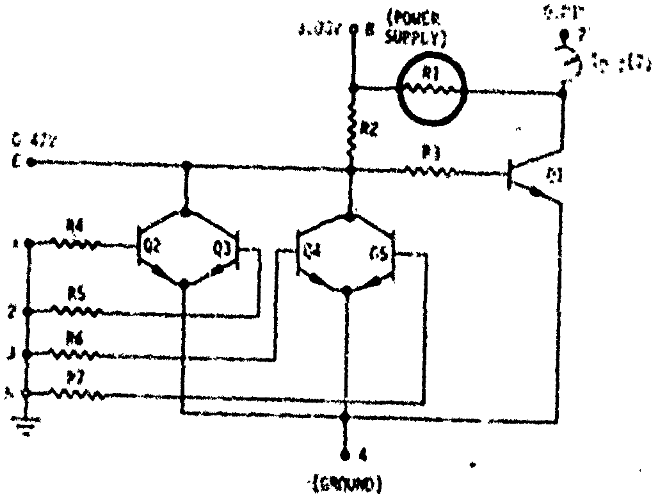
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



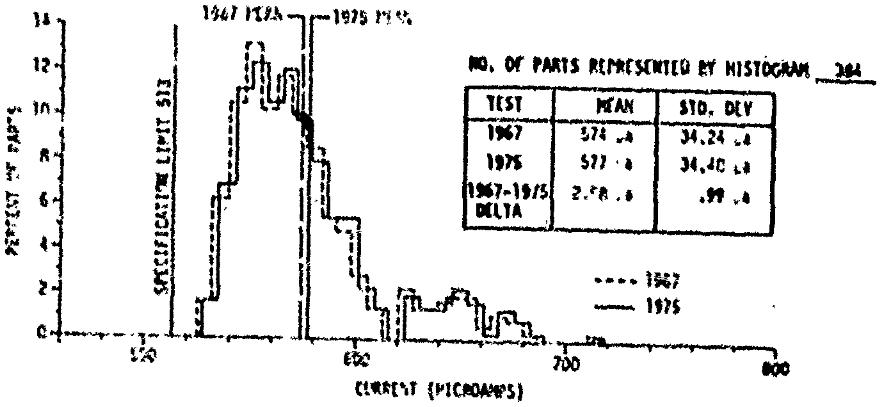
c. 1967 - 1975 CHANGE IN I_{IN}(I)

FIGURE 3-22. HISTOGRAM COMPARISON OF I_{IN}(I)

- FOUR INPUT GATE -



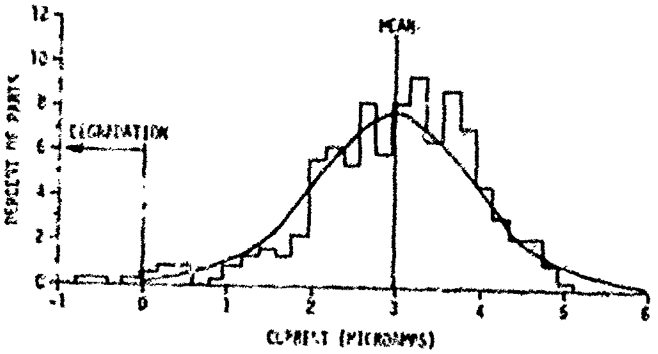
a SCHEMATIC FOR $I_{OUT}(7)$ TEST (R_1 RESISTANCE CHECK)



NO. OF PARTS REPRESENTED BY HISTOGRAM 384

TEST	MEAN	STD. DEV
1967	574 µA	34.24 µA
1975	577 µA	34.40 µA
1967-1975 DELTA	2.[illegible]8 µA	.99 µA

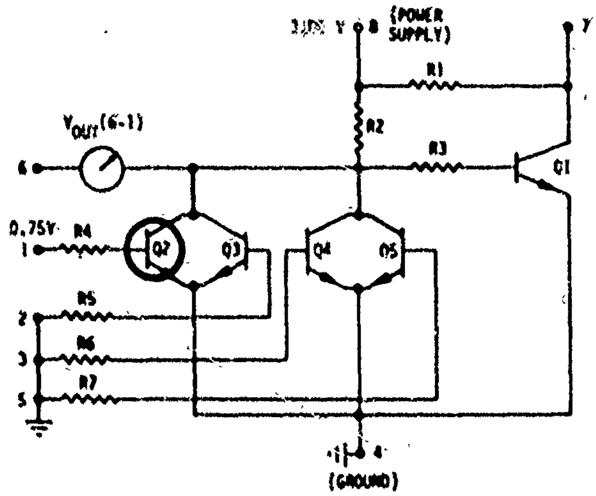
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



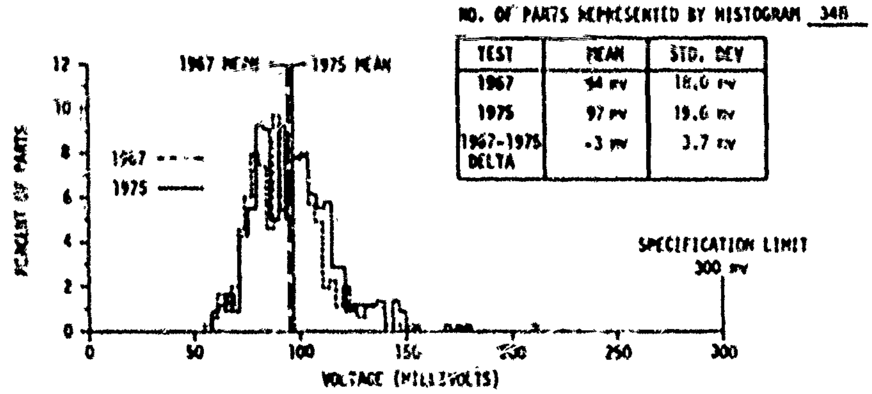
c. 1967-1975 CHANGE IN $I_{OUT}(7)$

FIGURE 3-23. HISTOGRAM COMPARISON OF $I_{OUT}(7)$

4 - INPUT GATE



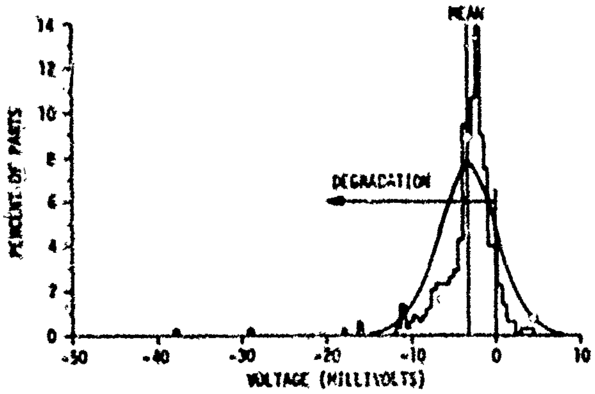
a. SCHEMATIC FOR V_{OUT}(6-1) TEST (Q2 VOLTAGE DROP AT MINIMUM "ON" CONDITION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 348

TEST	MEAN	STD. DEV
1967	94 mv	18.0 mv
1975	97 mv	19.6 mv
1967-1975 DELTA	-3 mv	3.7 mv

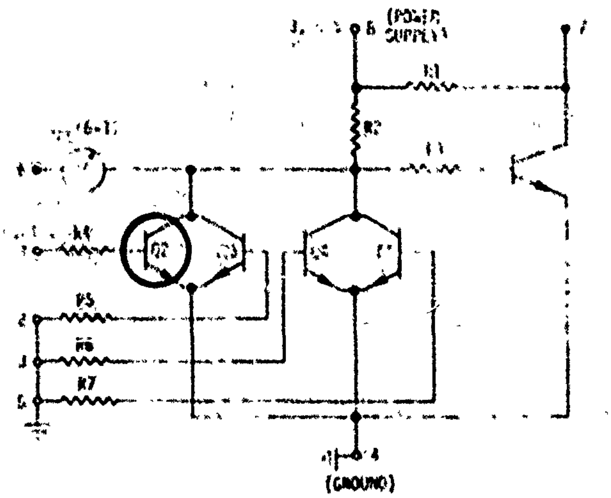
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



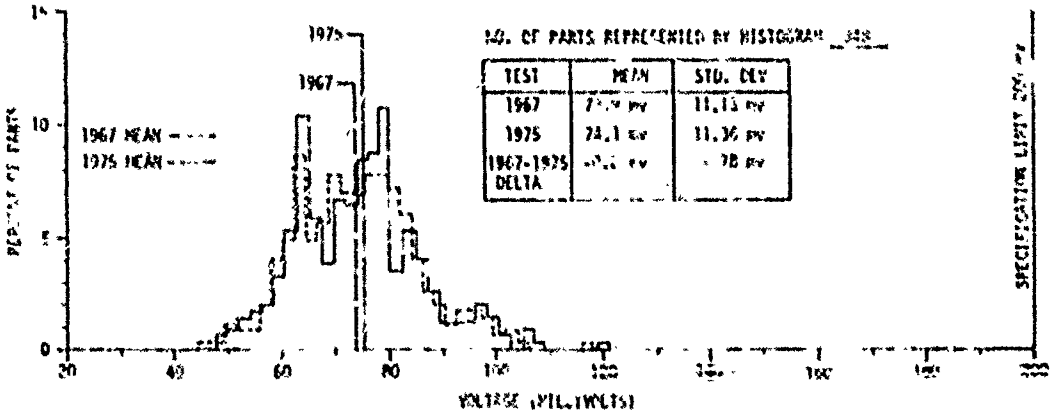
c. 1967 - 1975 CHANGE IN V_{OUT}(6-1)

FIGURE 3-24. HISTOGRAM COMPARISON OF V_{OUT}(6-1)

- FOUR-INPUT GATE -



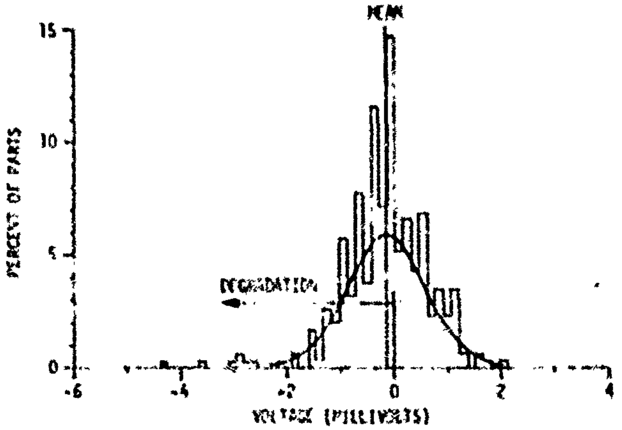
a. SCHEMATIC FOR V_{OL} (6-1) TEST (Q2 VOLTAGE DROP AT SATURATION)



NO. OF PARTS REPRESENTED BY HISTOGRAM [illegible]

TEST	MEAN	STD. DEV
1967	[illegible] mv	11.13 mv
1975	74.1 mv	11.36 mv
1967-1975 DELTA	[illegible] mv	[illegible] mv

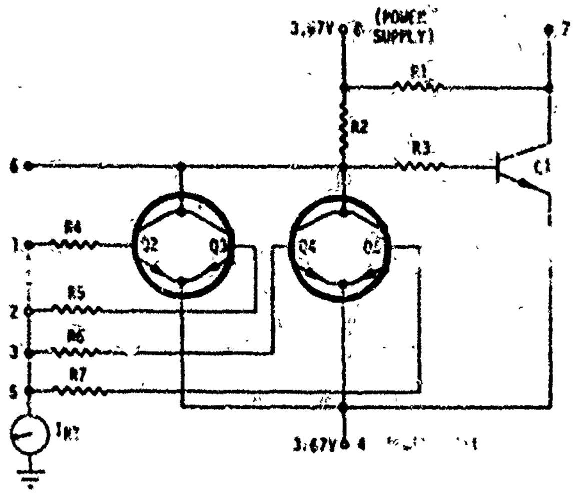
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



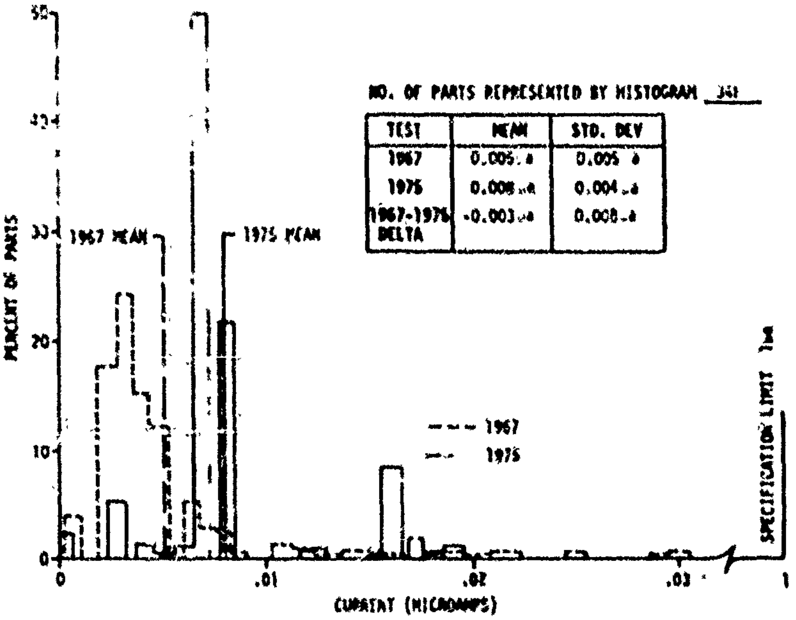
c. 1967 - 1975 CHANGE IN V_{OL} (6-1)

FIGURE 3-25. HISTOGRAM COMPARISON OF V_{OL} (6-1)

- FOUR-INPUT GATE -



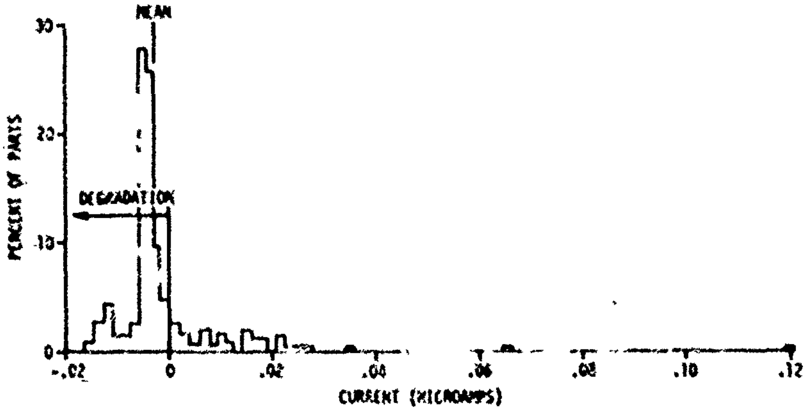
a. SCHEMATIC FOR I_{RT} TEST (Q2+Q3+Q4+Q5 BASE EMITTER JUNCTION LEAKAGE CURRENT



NO. OF PARTS REPRESENTED BY HISTOGRAM 341

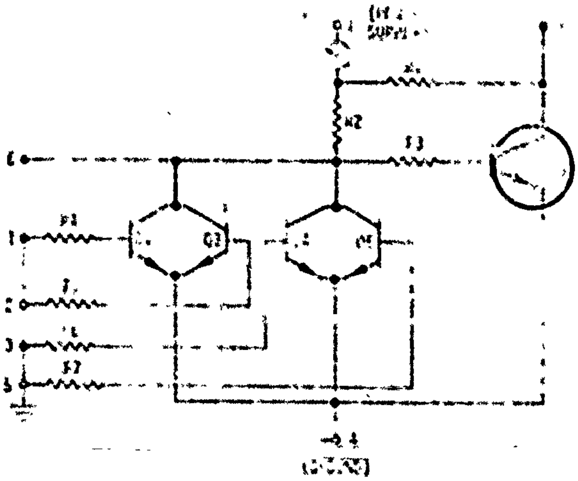
TEST	MEAN	STD. DEV
1967	0.005 μa	0.005 μa
1975	0.008 μa	0.004 μa
1967-1975 DELTA	-0.003 μa	0.008 μa

b. DISTRIBUTION OF PARTS: 1975 VS. 1967 TEST

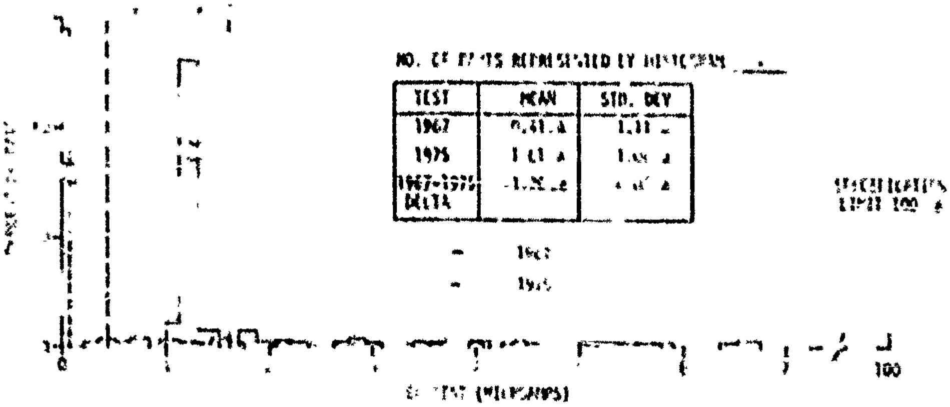


c. 1967-1975 CHANGE IN I_{RT}

FIGURE 3-26. HISTOGRAM COMPARISON OF I_{RT}
FOUR-INPUT GATE

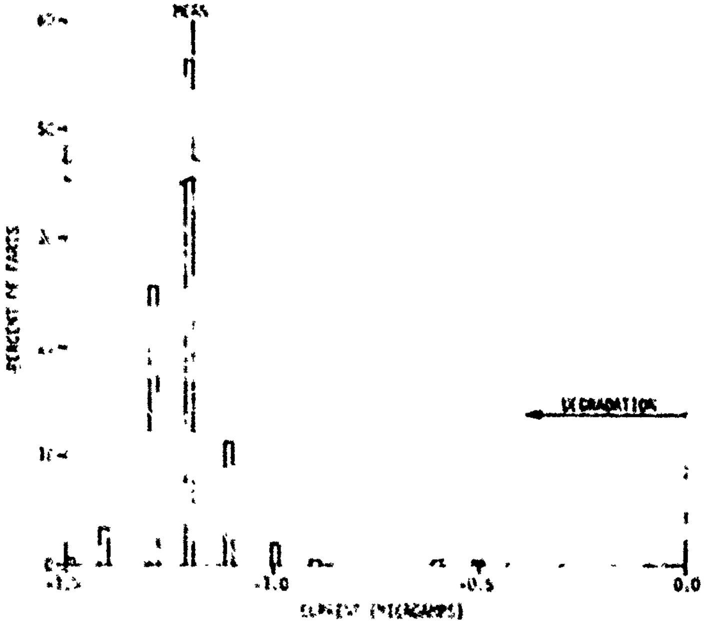


a. SCHEMATIC FOR $I_L(8)$ TEST (CT LEAKAGE CURRENT AT JUST BELOW MAXIMUM "OFF" CONDITION)



TEST	MEAN	STD. DEV
1967	0.41 µA	1.11 µA
1975	1.[illegible] µA	1.[illegible] µA
1967-1975 DELTA	-1.[illegible] µA	[illegible] µA

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



c. 1967-1975 CHANGE IN $I_L(8)$

FIGURE 3-27. HISTOGRAM COMPARISON OF $I_L(8)$

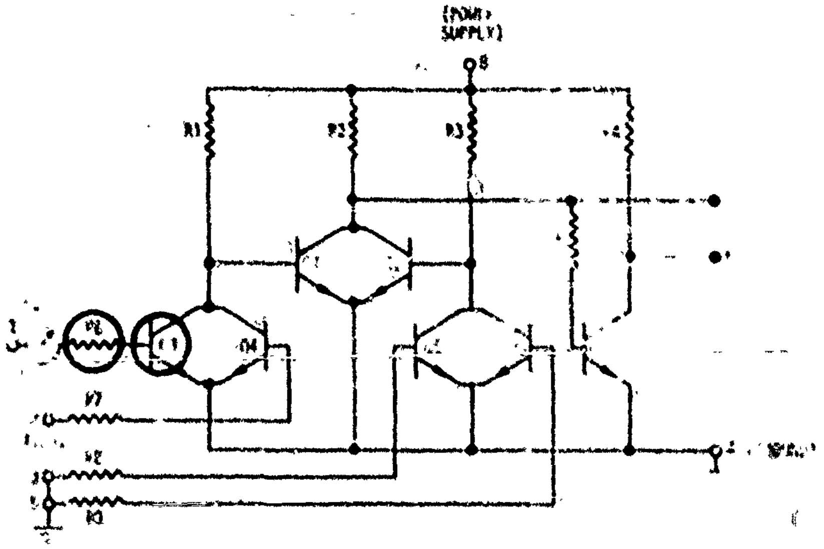
FOUR-INPUT GATE

TABLE 3-XIV. EVALUATION OF HISTOGRAM COMPARISONS FOR THE HALF ADDER

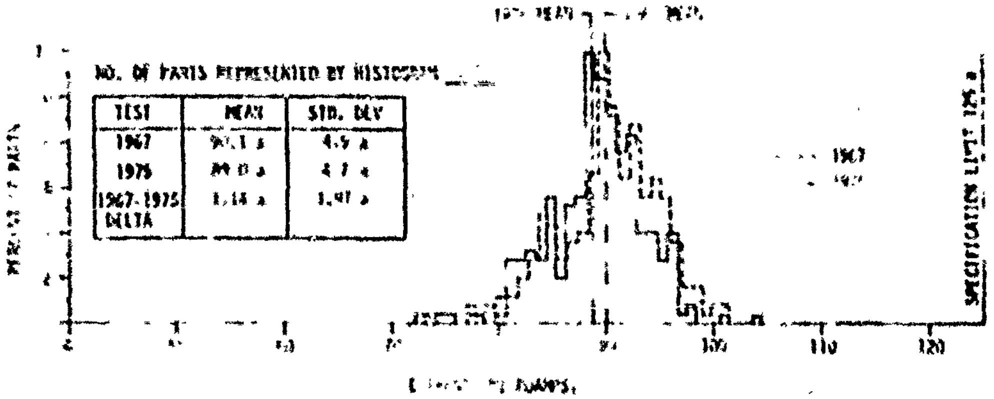
LEGEND	
✓	SLIGHT TREND
✓✓	MODERATE TREND
✓✓✓	PRONOUNCED TREND

PARAMETER (FIGURE NO.)	* TRENDS OBSERVED IN HISTOGRAM COMPARISONS						TECHNICAL ASSESSMENT
	TYPICAL MEASUREMENT DIFFERENCES			TYPICAL PARAMETER DRIFT			
	1967 - 1975 HISTOGRAMS SIMILAR IN SHAPE	SMALL SHIFT IN MEAN ATTRIBUTABLE TO MEASUREMENT DIFFERENCES	NEAR NORMAL DISTRIBUTION OF 1967-1975 CHANGES	1975 HISTOGRAM SHIFTED AND SKEWED TOWARD SPEC LIMIT	SHIFT IN 1975 MEAN TOWARD REDUCED PERFORMANCE	DISTRIBUTION OF 1967-1975 CHANGES SKEWED TOWARD DEGRADATION	
$I_{IN}(1)$ (3-28)	✓✓	✓✓	✓				NO MEASURABLE DRIFT
$I_{IN}(3)$ (3-29)	✓✓	✓✓	✓				NO MEASURABLE DRIFT
$I_{OUT}(7-1)$ (3-30)	✓✓	✓	✓				NO MEASURABLE DRIFT
$V_{OL}(6)$ (3-31)	✓✓	✓	✓✓				NO MEASURABLE DRIFT
I_{RT} (3-32)	✓	✓	✓				NO SIGNIFICANT DRIFT
$I_L(8)$ (3-33)	✓	✓	✓				NO SIGNIFICANT DRIFT

*NOTE: CHECKS APPEARING IN FIRST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO NORMAL MEASUREMENT ERRORS; CHECKS IN LAST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO PARAMETER DRIFT

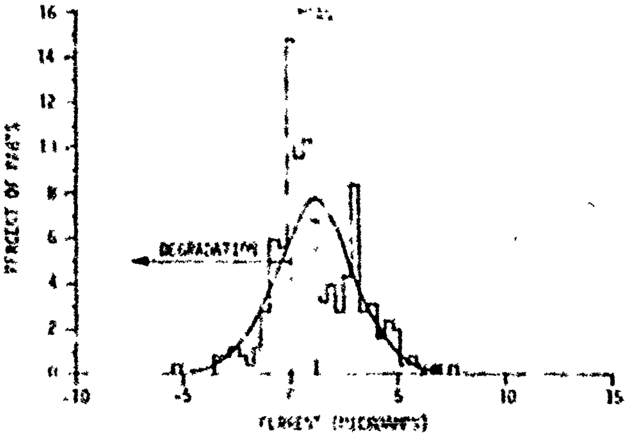


a. SCHEMATIC FOR I_{IN}(1) TEST (R_6 RESISTANCE [illegible] SET IN TRUE COLLECTOR SATURATION VOLTAGE)



TEST	MEAN	STD. DEV
1967	90.1 a	4.5 a
1975	89.0 a	4.7 a
1967-1975 DELTA	1.14 a	1.41 a

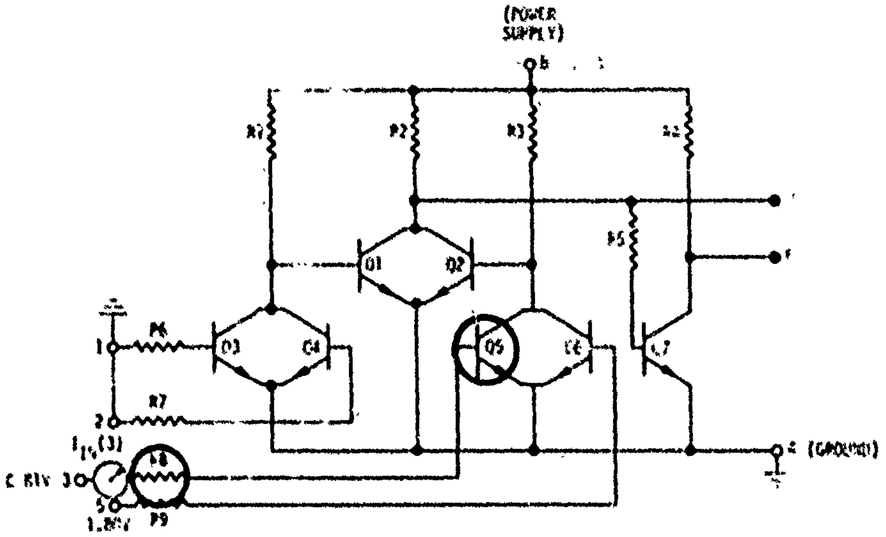
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



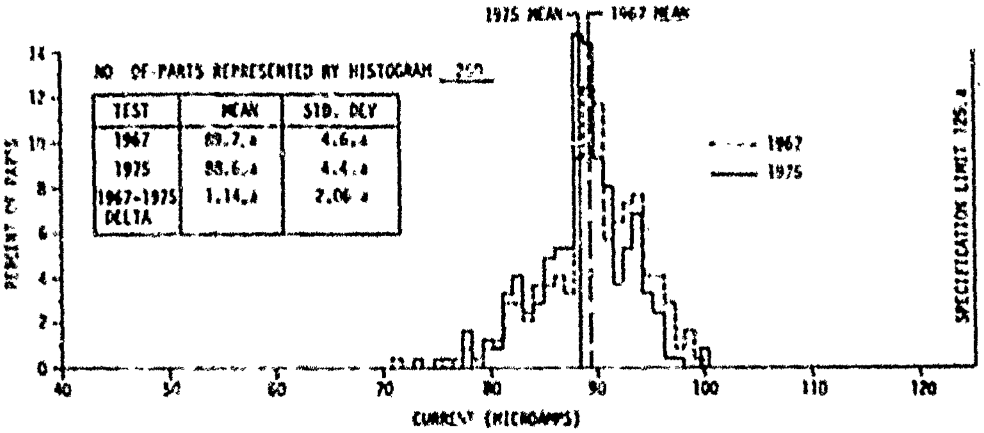
c. 1967 - 1975 CHANGE IN I_{IN}(1)

FIGURE 3-28. HISTORICAL COMPARISON OF I_{IN}(1)

- HALF LADDER -



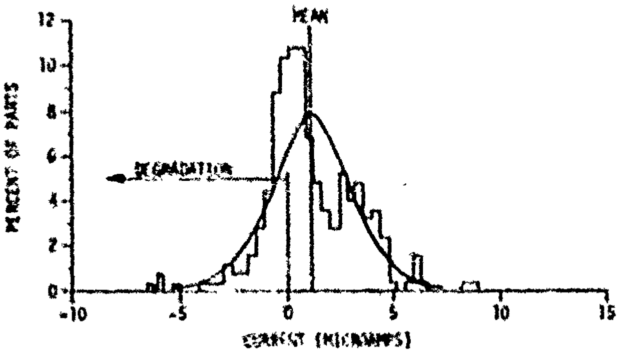
a SCHEMATIC FOR $I_{IN}(3)$ TEST (R8 RESISTANCE + Q5 BASE EMITTER JUNCTION LEAKAGE CHECK AT SATURATION VOLTAGE)



NO. OF PARTS REPRESENTED BY HISTOGRAM 250

TEST	MEAN	STD. DEV
1967	89.7 μa	4.6 μa
1975	88.6 μa	4.4 μa
1967-1975 DELTA	1.14 μa	2.06 μa

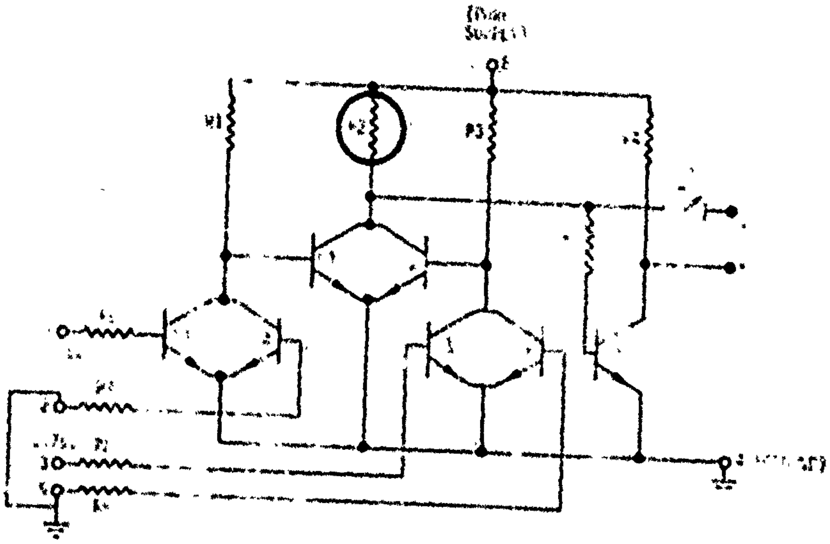
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



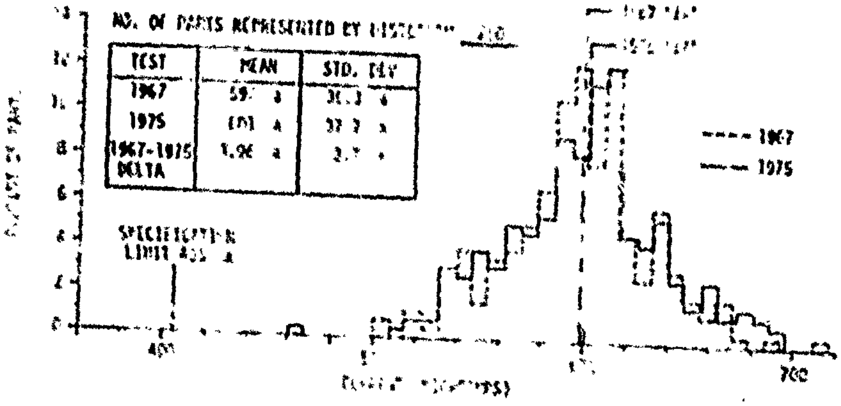
c. 1967 - 1975 CHANGE IN $I_{IN}(3)$

FIGURE 3-2[illegible]. HISTOGRAM COMPARISON OF $I_{IN}(3)$

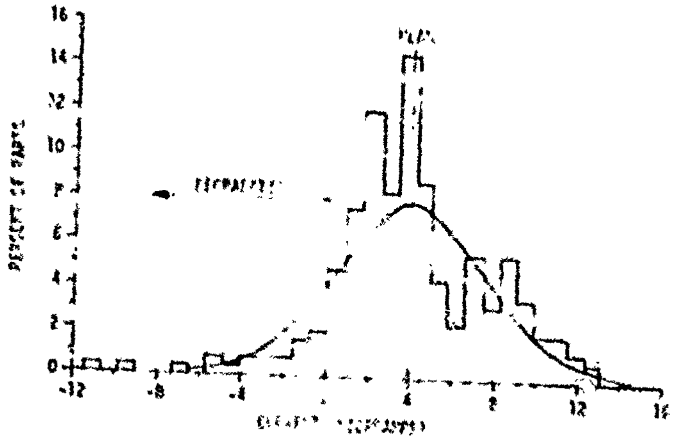
- HALF ADDER -



a. SCHEMATIC FOR IOUT(7-1) TEST (b) RESISTANCE CHECK)



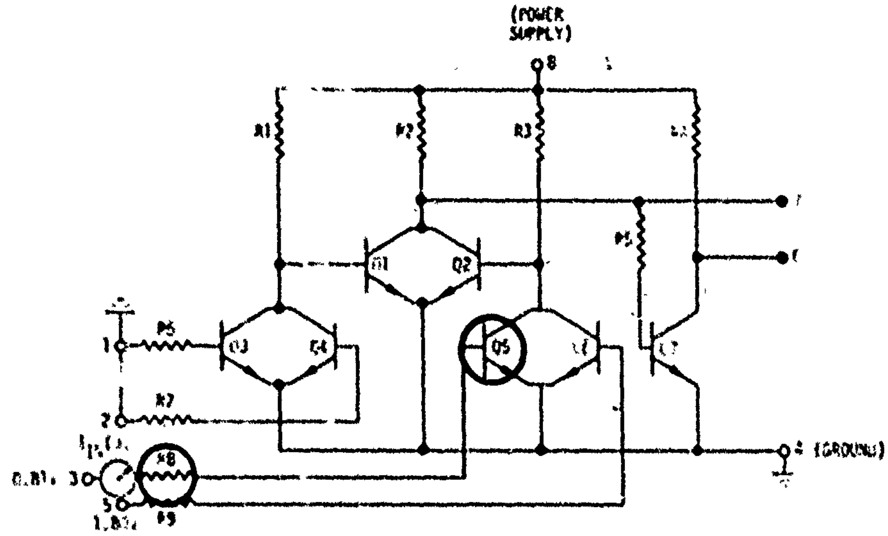
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



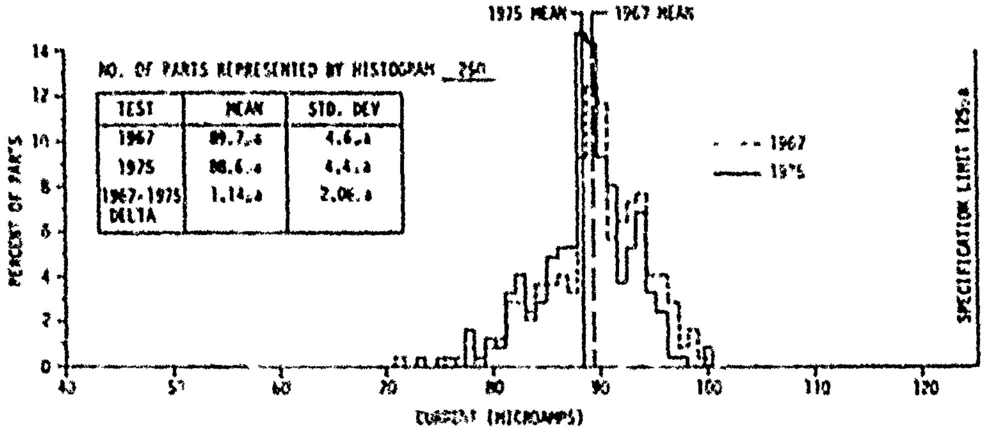
c. 1967-1975 CHANGE IN IOUT(7-1)

FIGURE 2-20. HISTOGRAM COMPARISON OF IOUT(7-1)

HALF ADDER



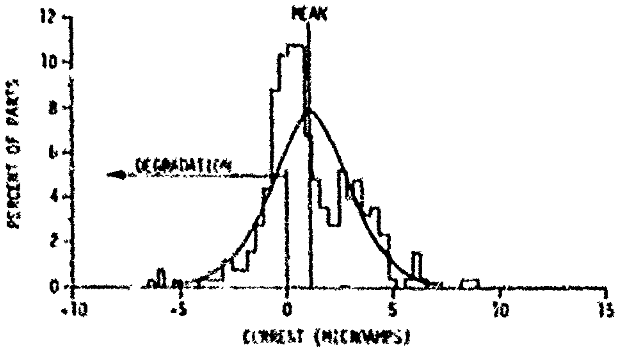
a SCHEMATIC FOR $I_{IN}(3)$ TEST (R8 RESISTANCE + Q5 BASE EMITTER JUNCTION LEAKAGE CHECK AT SATURATION VOLTAGE)



NO. OF PARTS REPRESENTED BY HISTOGRAM 250

TEST	MEAN	STD. DEV
1967	89.7µa	4.6µa
1975	88.6µa	4.4µa
1967-1975 DELTA	1.14µa	2.06µa

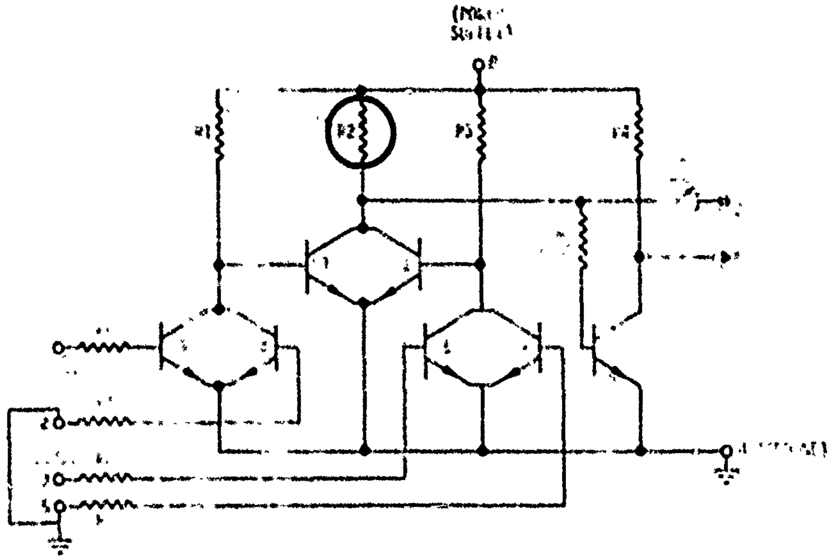
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



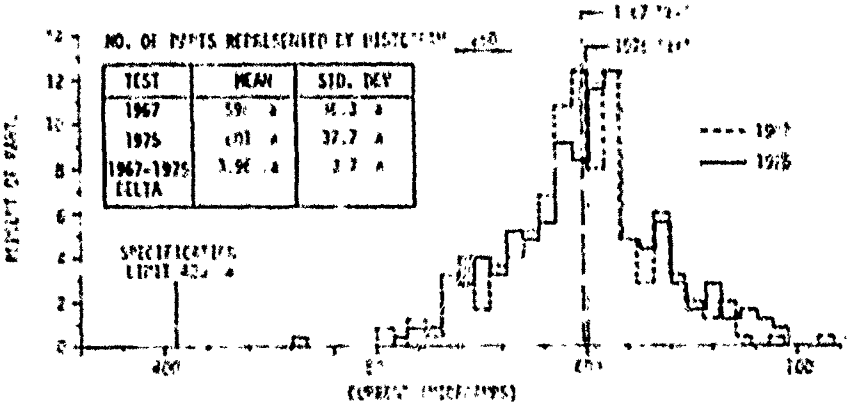
c. 1967 - 1975 CHANGE IN $I_{IN}(3)$

FIGURE 3-2. HISTOGRAM COMPARISON OF $I_{IN}(3)$

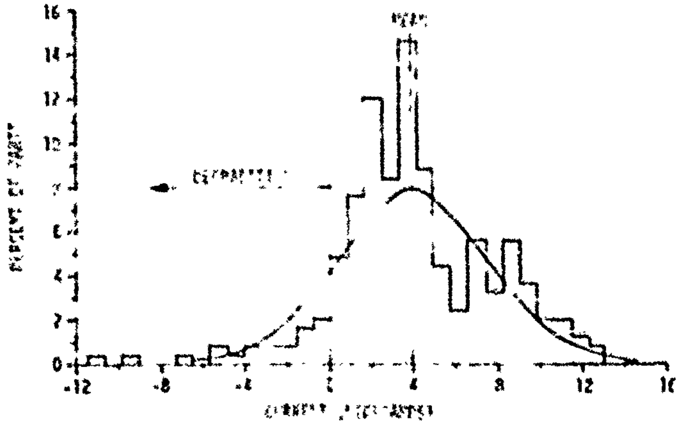
- HALF ADDER -



a. SCHEMATIC FOR I_{OUT}(7-1) TEST (R2 RESISTANCE CHECK)



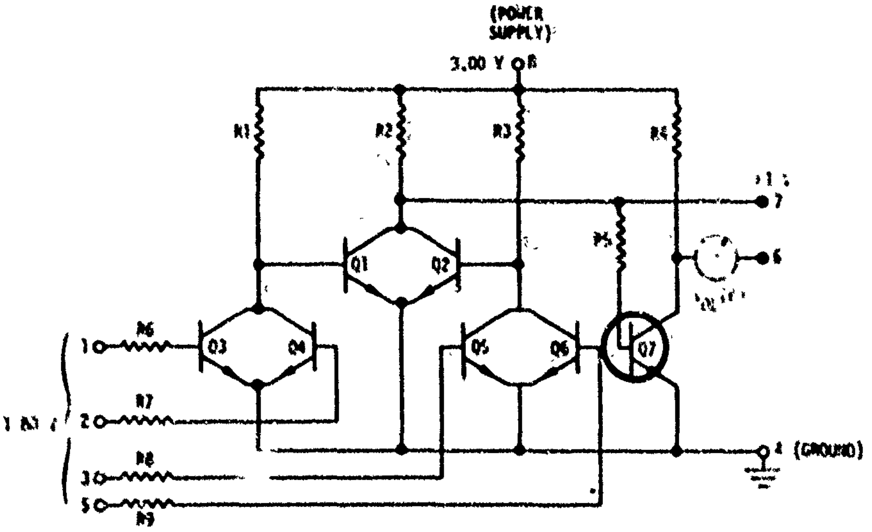
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



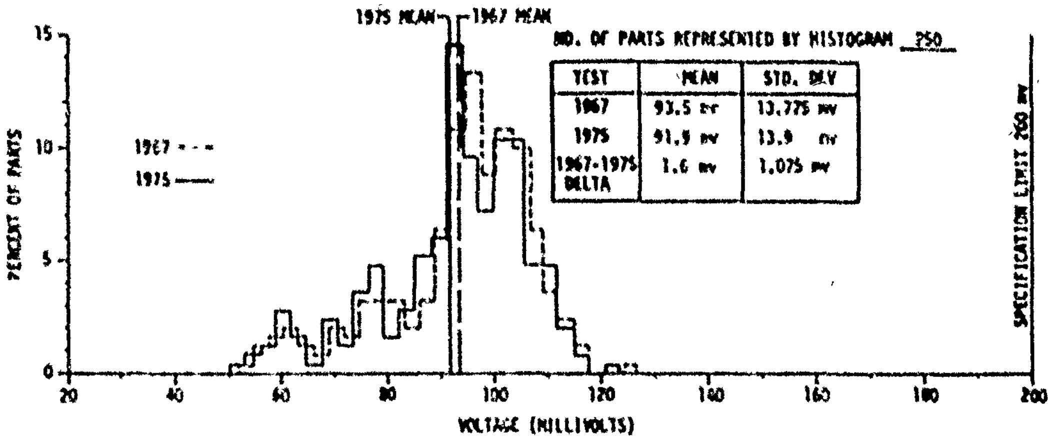
c. 1967-1975 CHANGE IN I_{OUT}(7-1)

FIGURE 3-20. HISTOGRAM COMPARISON OF I_{OUT}(7-1)

HALF ADDER



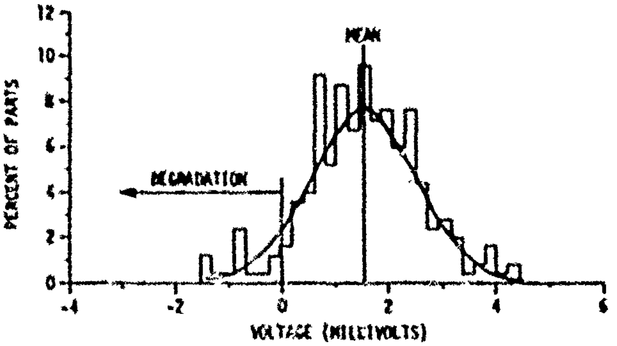
a. SCHEMATIC FOR V_{OL}(6) TEST (Q7 VOLTAGE DROP AT SATURATION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 250

TEST	MEAN	STD. DEV
1967	93.5 mv	13.775 mv
1975	91.9 mv	13.9 mv
1967-1975 DELTA	1.6 mv	1.075 mv

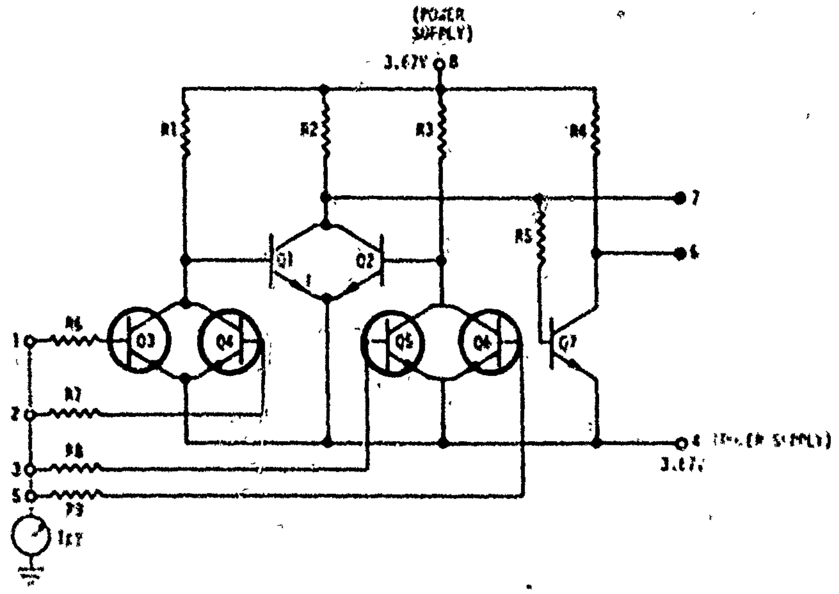
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



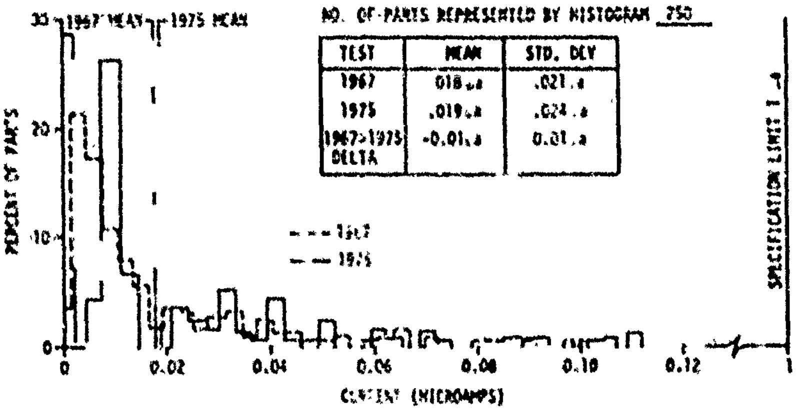
c. 1967 - 1975 CHANGE IN V_{OL}(6)

FIGURE 3-31. HISTOGRAM COMPARISON OF V_{OL}(6)

- HALF ADDER -



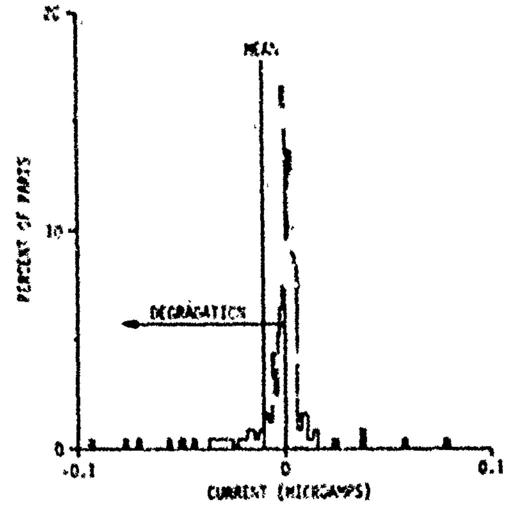
a. SCHEMATIC FOR I_{RT} TEST (Q3+Q4+Q5+Q6 BASE EMITTER JUNCTION LEAKAGE CHECK)



NO. OF PARTS REPRESENTED BY HISTOGRAM 250

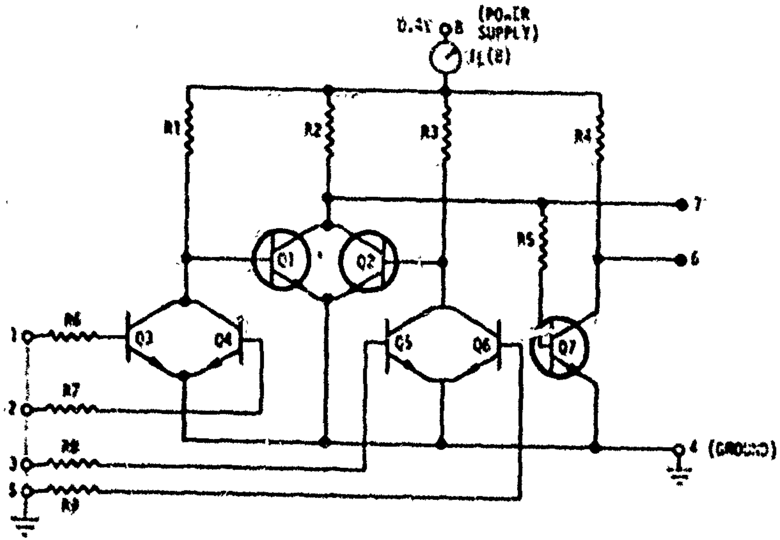
TEST	MEAN	STD. DEV
1967	018 μa	.021 μa
1975	.019 μa	.024 μa
1967>1975 DELTA	-0.01 μa	0.01 μa

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

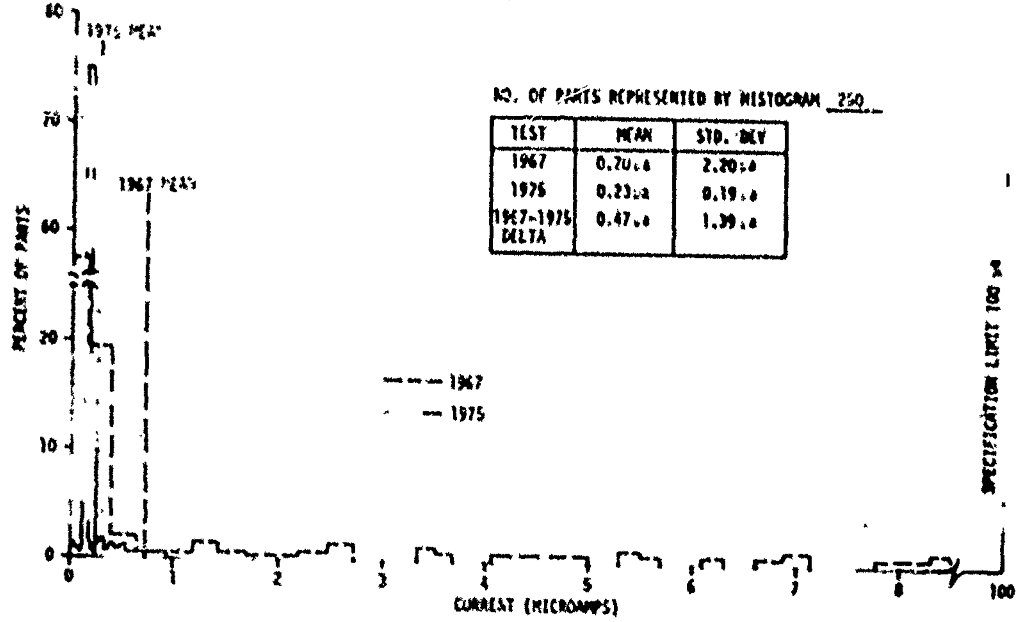


c. 1967-1975 CHANGE IN I_{RT}

FIGURE 3-32 HISTOGRAM COMPARISON OF I_{RT}
HALF ADDER



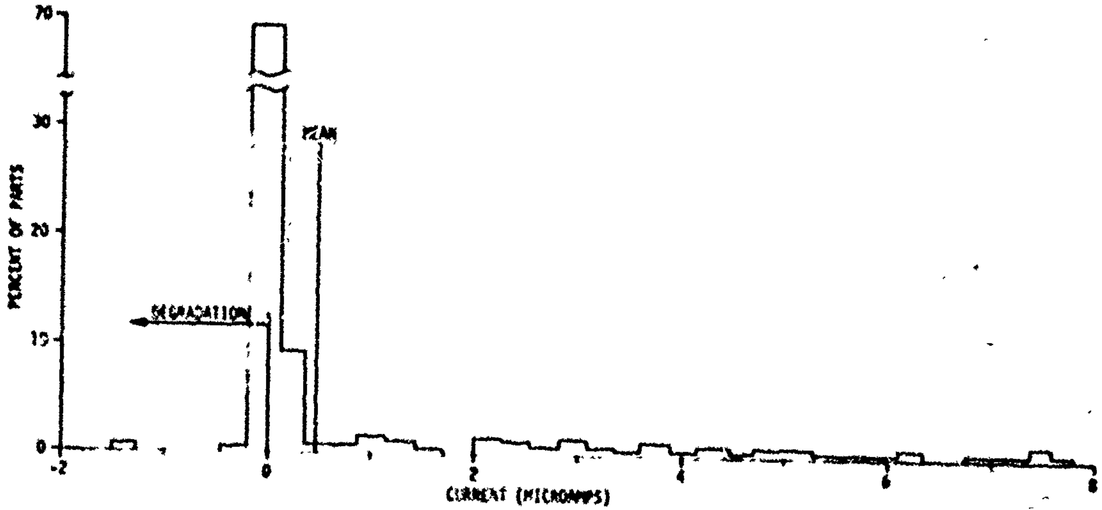
a. SCHEMATIC FOR $I_L(8)$ TEST (Q1+Q2+Q7 LEAKAGE CURRENT AT JUST BELOW MAXIMUM "OFF" CONDITION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 250

TEST	MEAN	STD. DEV
1967	0.70μa	2.20μa
1975	0.23μa	0.19μa
1967-1975 DELTA	0.47μa	1.39μa

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



c. 1967-1975 CHANGE IN $I_L(8)$

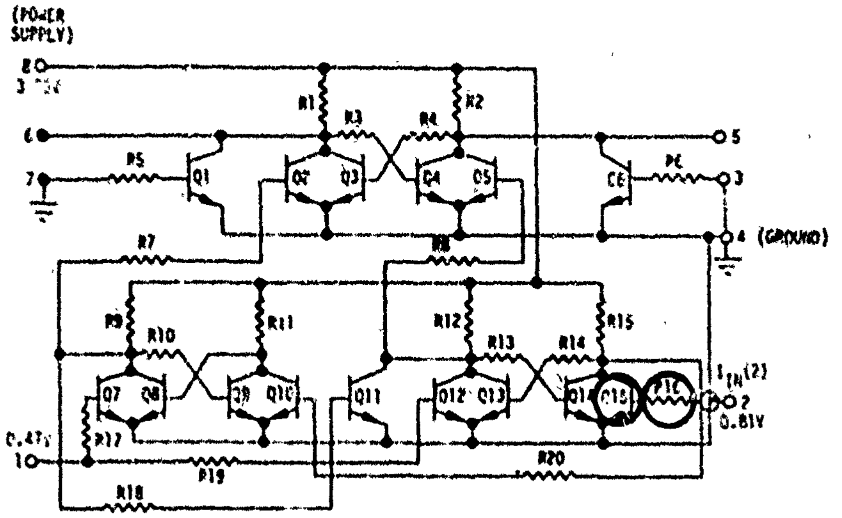
FIGURE 3-33. HISTOGRAM COMPARISON OF $I_L(8)$ HALF ADDER

TABLE 3-XV. EVALUATION OF HISTOGRAM COMPARISONS FOR THE REGISTER

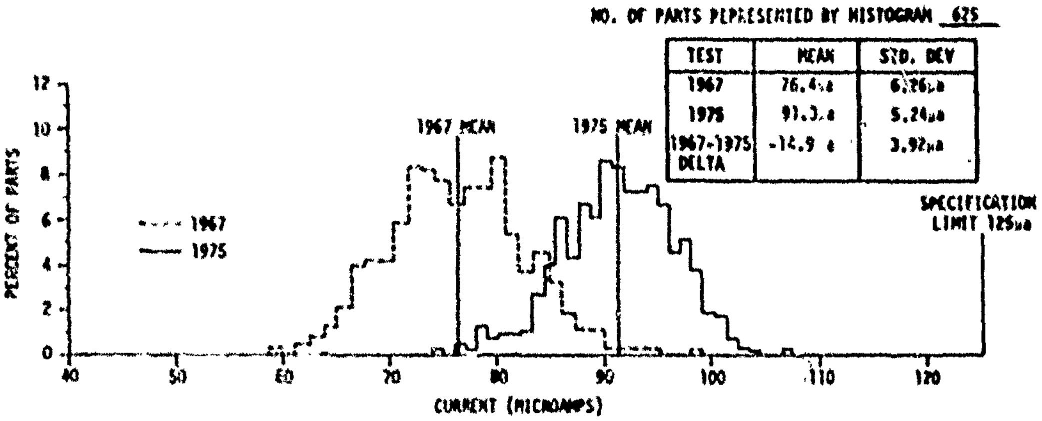
LEGEND	
✓	SLIGHT TREND
✓✓	MODERATE TREND
✓✓✓	PRONOUNCED TREND

PARAMETER (FIGURE NO.)	*TRENDS OBSERVED IN HISTOGRAM COMPARISONS						TECHNICAL ASSESSMENT
	TYPICAL MEASUREMENT DIFFERENCES			TYPICAL PARAMETER DRIFT			
	1967 - 1975 HISTOGRAMS SIMILAR IN SHAPE	SMALL SHIFT IN MEAN ATTRIBUTABLE TO MEASUREMENT DIFFERENCES	NEAR NORMAL DISTRIBUTION OF 1967-1975 CHANGES	1975 HISTOGRAM SHIFTED AND SKEWED TOWARD SPEC LIMIT	SHIFT IN 1975 MEAN TOWARD DEGRADED PERFORMANCE	DISTRIBUTION OF 1967-1975 CHANGES SKEWED TOWARD DEGRADATION	
I_{IN}(2) (3-34)	✓✓	✓✓✓	✓✓		✓✓✓		NO MEASURABLE DRIFT
I_{OUT}(6-1) (3-35)	✓✓✓	✓✓✓	✓		✓	✓	NO MEASURABLE DRIFT
V_{OUT}(5-1) (3-36)				✓✓	✓✓	✓✓	MODERATE DRIFT
V_{OL}(6-1) (3-37)	✓	✓	✓	✓	✓	✓	NO MEASURABLE DRIFT IN $+\sigma$ PARTS; SLIGHT DRIFT IN $-\sigma$ PARTS
I_{RT} (3-38)	✓	✓	✓				NO SIGNIFICANT DRIFT
I_L(8) (3-39)	✓	✓	✓				NO SIGNIFICANT DRIFT

*NOTE: CHECKS APPEARING IN FIRST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO NORMAL MEASUREMENT ERRORS; CHECKS IN LAST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO PARAMETER DRIFT

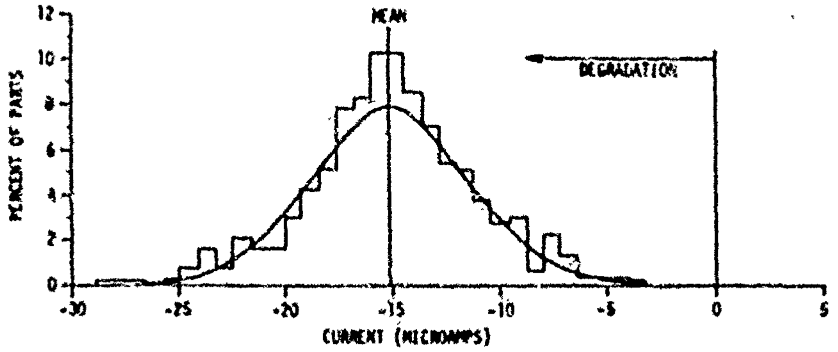


a. SCHEMATIC FOR $I_{IN}(2)$ TEST (R_{16} RESISTANCE + Q15 BASE EMITTER CHECK AT SATURATION VOLTAGE)



TEST	MEAN	STD. DEV
1967	76.4μa	6.26μa
1975	91.3μa	5.24μa
1967-1975 DELTA	-14.9μa	3.92μa

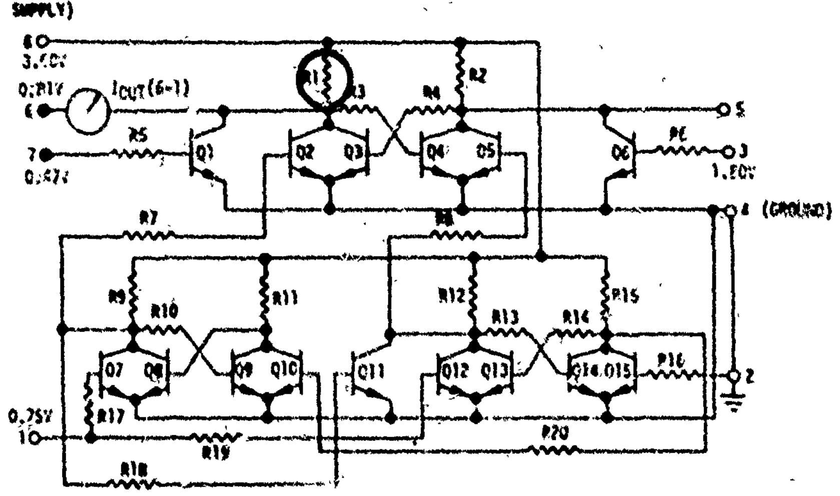
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



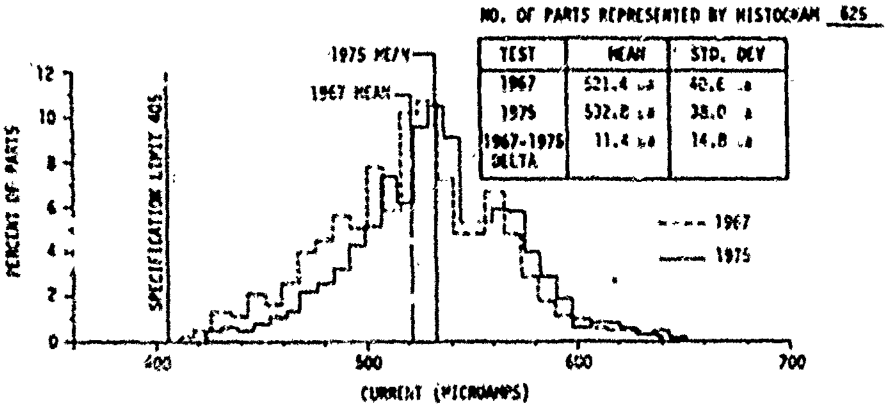
c. 1967 - 1975 CHANGE IN $I_{IN}(2)$

FIGURE 3-34. HISTOGRAM COMPARISON OF $I_{IN}(2)$

- REGISTER -



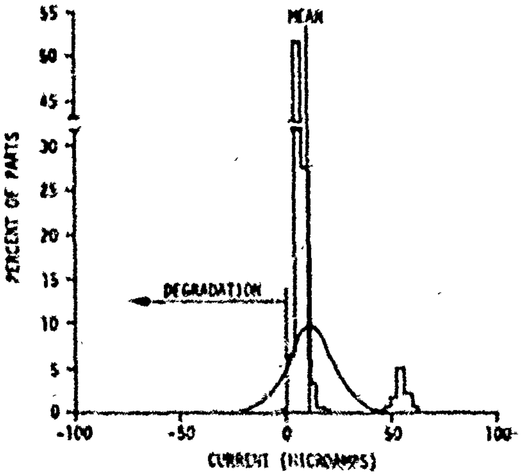
a. SCHEMATIC FOR $I_{OUT}(6-1)$ TEST (R_1 RESISTANCE CHECK)



NO. OF PARTS REPRESENTED BY HISTOGRAM 625

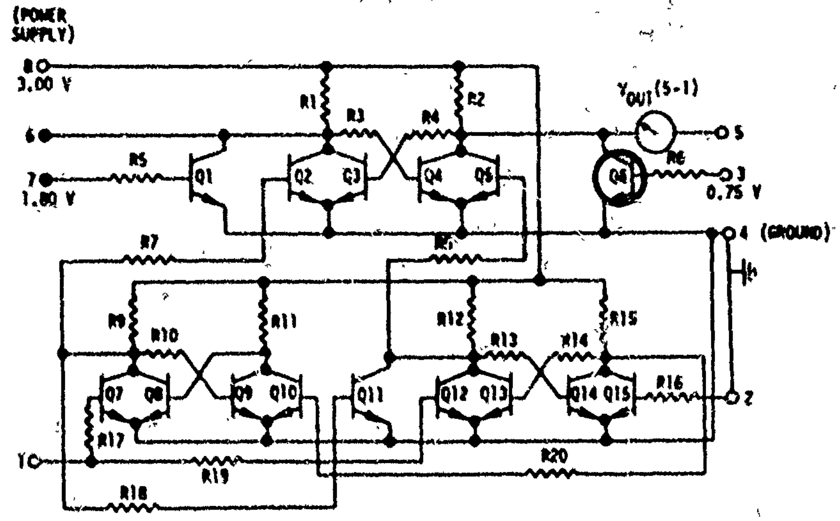
TEST	MEAN	STD. DEV
1967	521.4 µa	40.6 µa
1975	532.8 µa	38.0 µa
1967-1975 DELTA	11.4 µa	14.8 µa

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

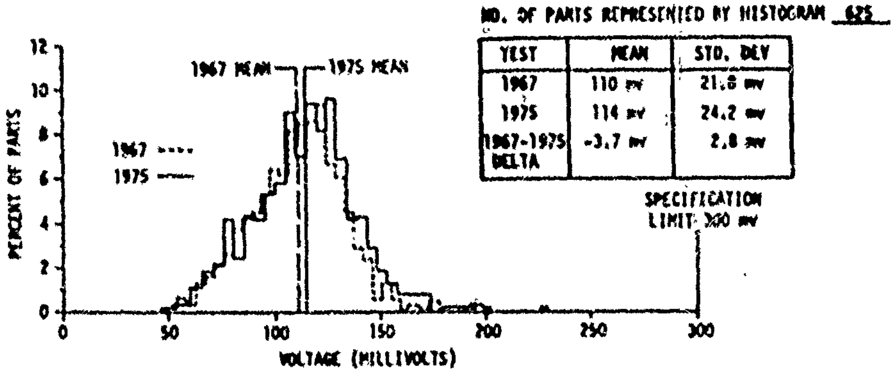


c. 1967-1975 CHANGE IN $I_{OUT}(6-1)$

FIGURE 3-35. HISTOGRAM COMPARISON OF $I_{OUT}(6-1)$ REGISTER



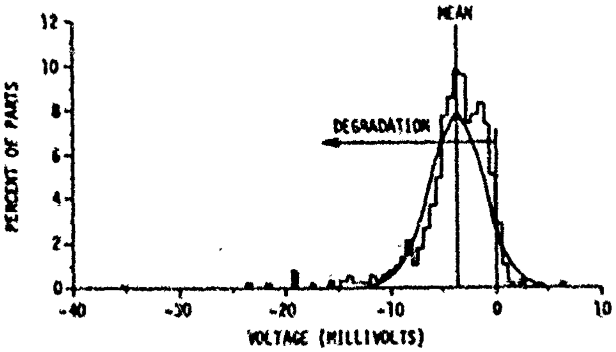
a. SCHEMATIC FOR V_{OUT} (5-1) TEST (Q6 VOLTAGE DROP AT MINIMUM "ON" CONDITION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 625

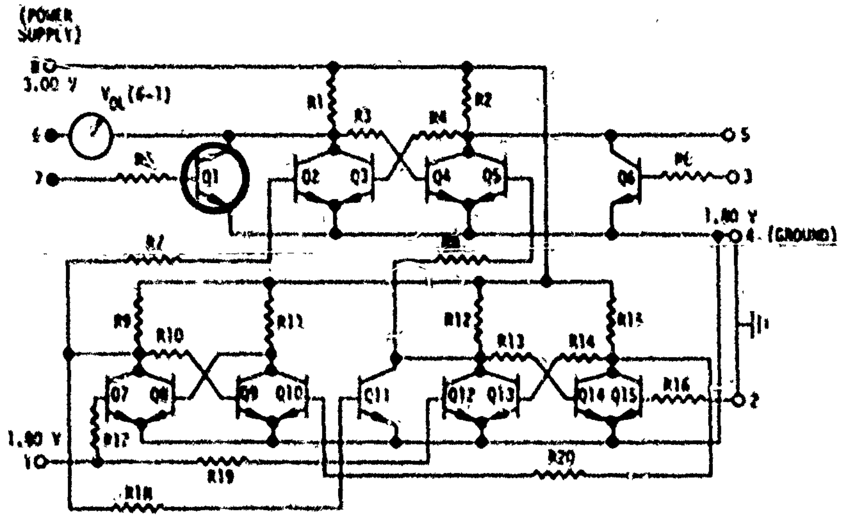
TEST	MEAN	STD. DEV
1967	110 mv	21.8 mv
1975	114 mv	24.2 mv
1967-1975 DELTA	-3.7 mv	2.8 mv

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

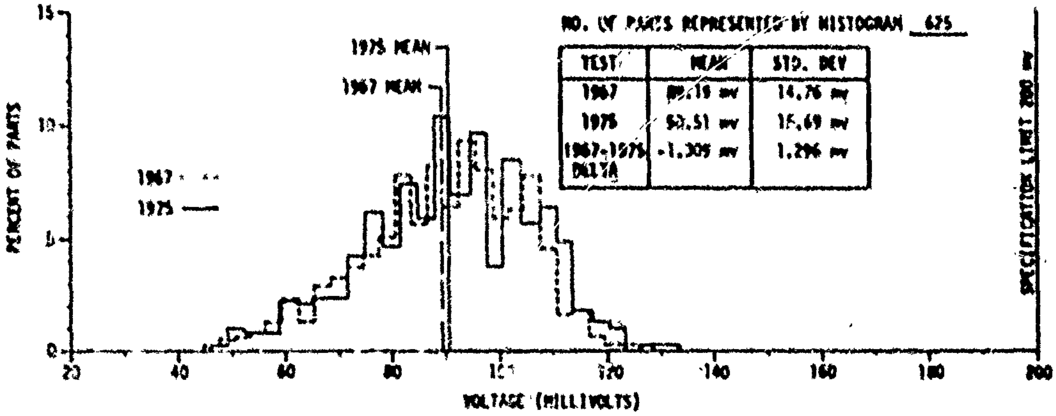


c. 1967 - 1975 CHANGE IN V_{OUT} (5-1)

FIGURE 3-36. HISTOGRAM COMPARISON OF V_{OUT} (5-1)



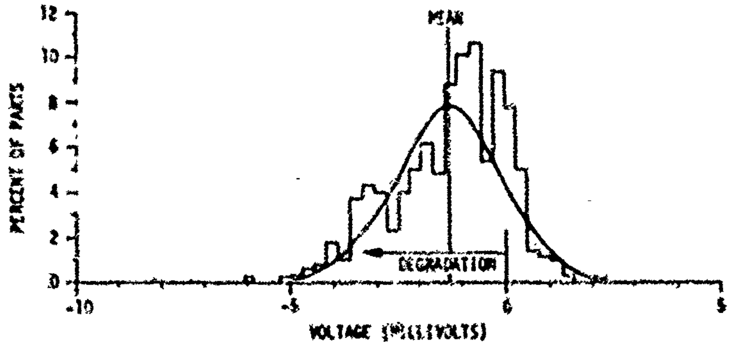
a. SCHEMATIC FOR V_{OL}(6-1) TEST (Q1 VOLTAGE DROP AT SATURATION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 625

TEST	MEAN	STD. DEV
1967	89.19 mv	14.76 mv
1975	90.51 mv	15.69 mv
1967-1975 DELTA	-1.309 mv	1.296 mv

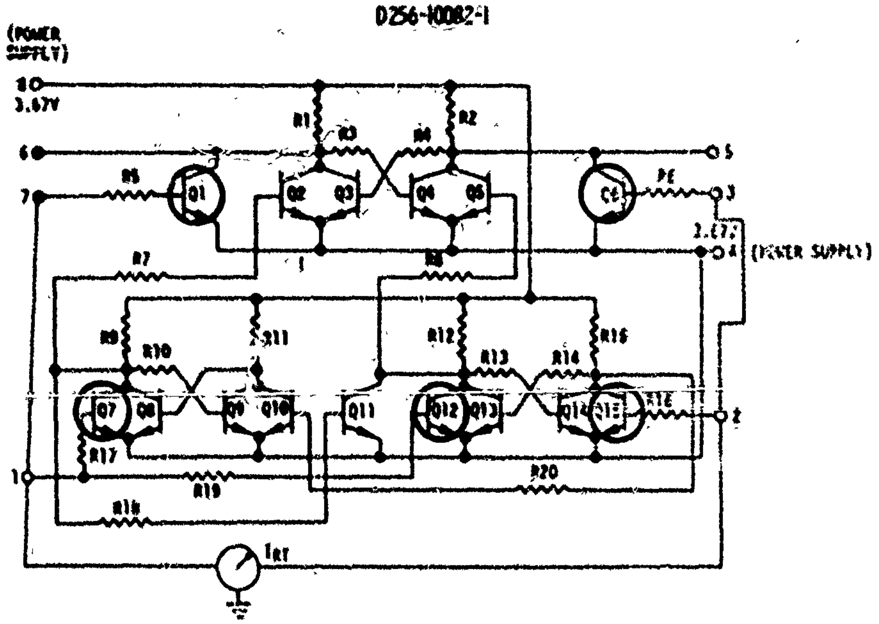
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



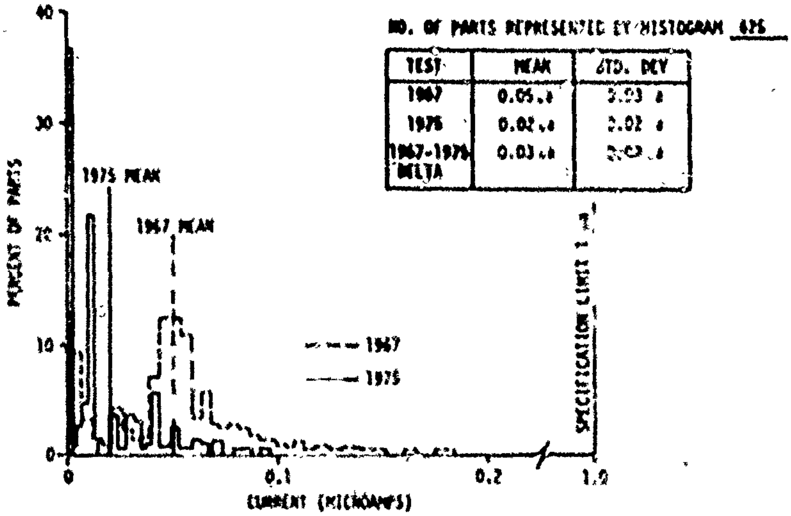
c. 1967 - 1975 CHANGE IN V_{OL}(6-1)

FIGURE 3-37. HISTOGRAM COMPARISON OF V_{OL}(6-1)

- RELVISTER -



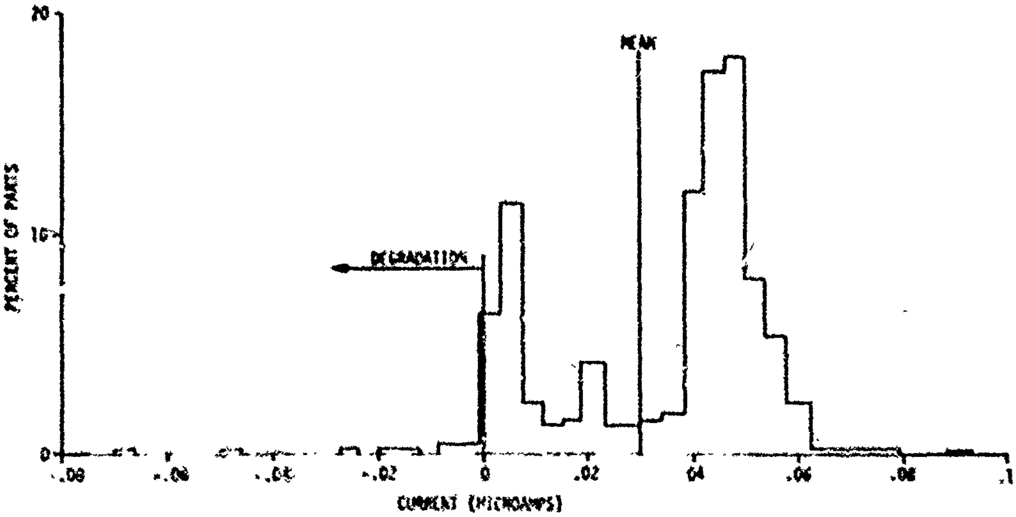
a. SCHEMATIC FOR I_{RT} TEST (Q1+Q6+q7+Q12+Q15 BASE EMITTER JUNCATION LEAKAGE CHECK



NO. OF PARTS REPRESENTED BY HISTOGRAM 625

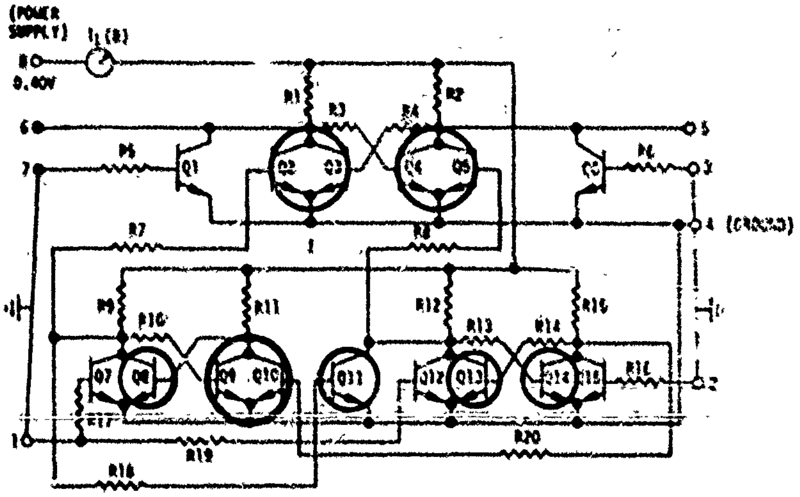
TEST	MEAN	STD. DEV
1967	0.05 μA	0.03 μA
1975	0.02 μA	0.02 μA
1967-1975 DELTA	0.03 μA	[illegible]

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

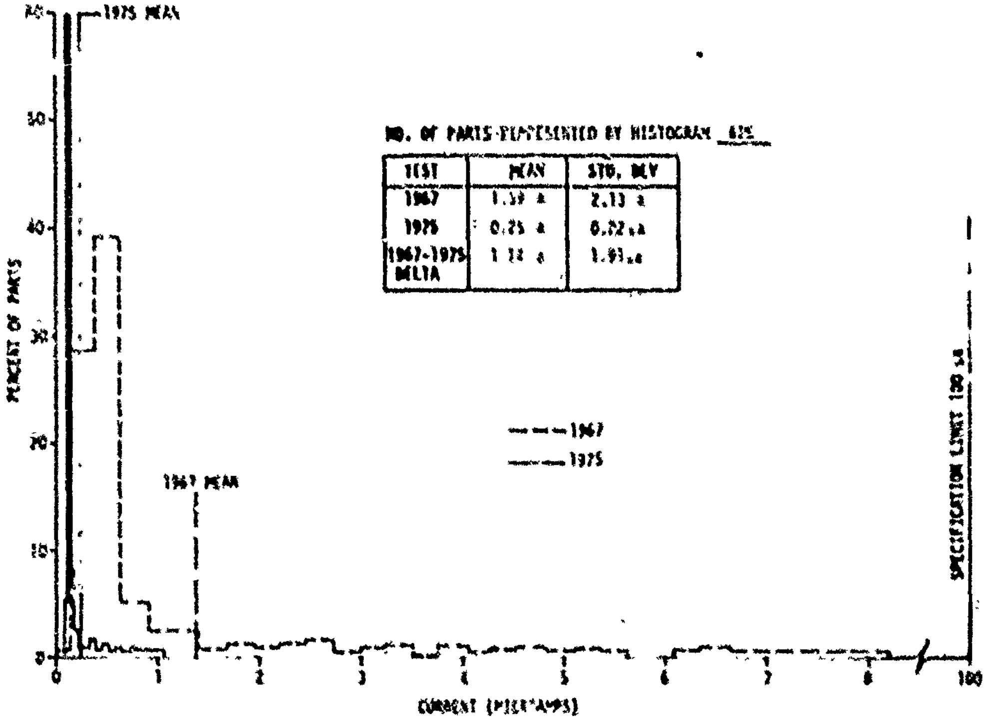


c. 1967-1975 CHANGE IN I_{RT}

FIGURE 3-38. HISTOGRAM COMPARISON OF I_{RT}



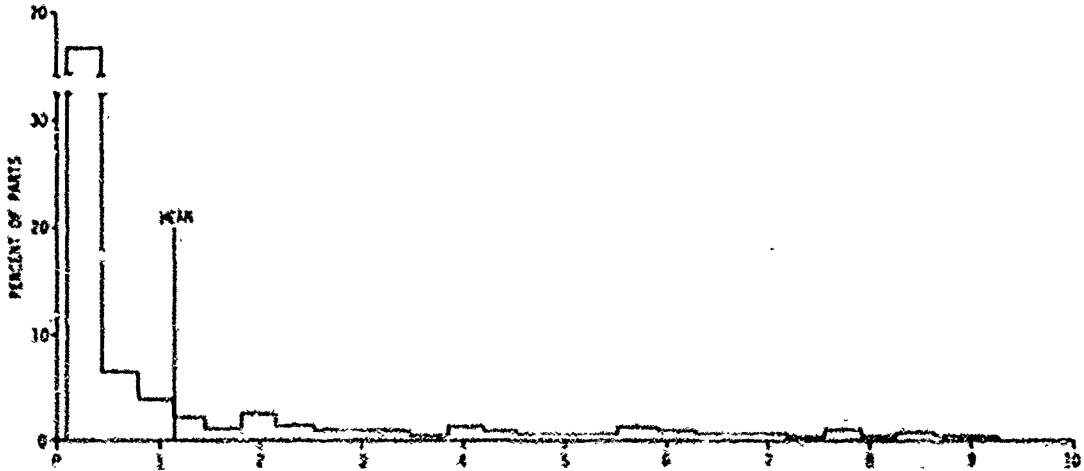
a. SCHEMATIC FOR $I_L(B)$ TEST (Q2+Q3+Q4+Q5+Q8+Q9+Q10+Q11+Q13+Q14 LEAKAGE CURRENT AT JUST BELOW MAXIMUM "OFF" CONDITION)



NO. OF PARTS REPRESENTED BY HISTOGRAM 625

TEST	MEAN	STD. DEV
1967	1.39 μA	2.13 μA
1975	0.25 μA	0.72 μA
1967-1975 DELTA	1.14 μA	1.93 μA

b. DISTRIBUTION OF PARTS: 1975 VS. 1967 TEST



c. 1967-1975 CHANGE IN $I_L(B)$

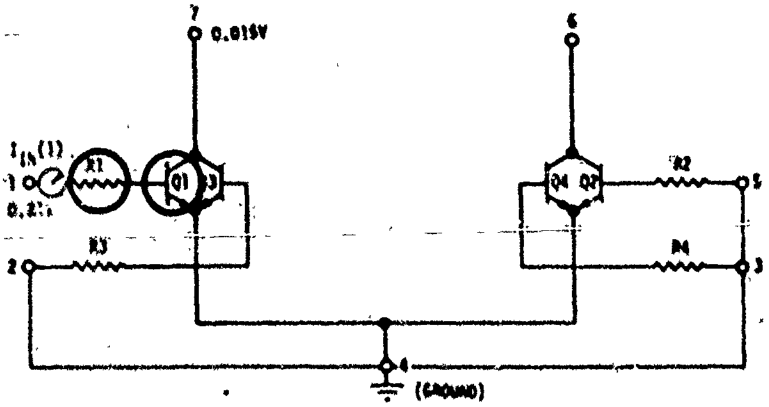
FIGURE 3-59. HISTOGRAM COMPARISON OF $I_L(B)$

TABLE 3-XVI. EVALUATION OF HISTOGRAM COMPARISONS FOR THE EXPANDER

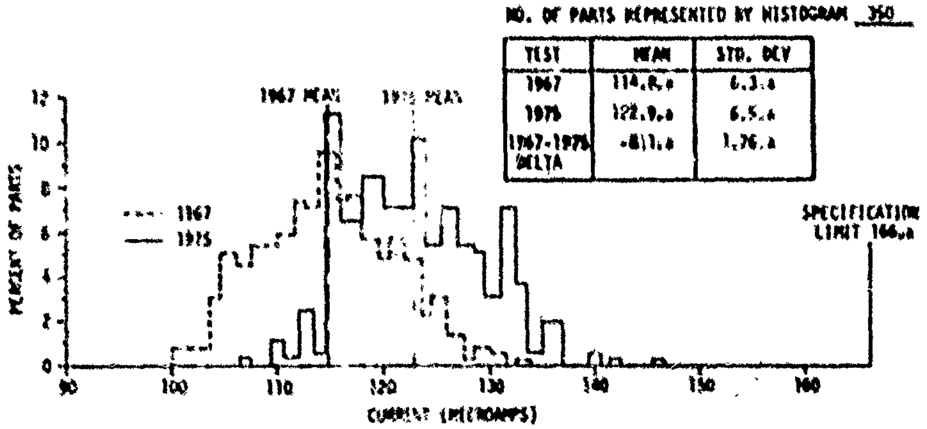
LEGEND	
✓	SLIGHT TREND
✓✓	MODERATE TREND
✓✓✓	PRONOUNCED TREND

PARAMETER (FIGURE NO.)	*TRENDS OBSERVED IN HISTOGRAM COMPARISONS						TECHNICAL ASSESSMENT
	TYPICAL MEASUREMENT DIFFERENCES			TYPICAL PARAMETER DRIFT			
	1967 - 1975 HISTOGRAMS SIMILAR IN SHAPE	SMALL SHIFT IN MEAN ATTRIBUTABLE TO MEASUREMENT DIFFERENCES	NEAR NORMAL DISTRIBUTION OF 1967-1975 CHANGES	1975 HISTOGRAM SHIFTED AND SKEWED TOWARD SPEC LIMIT	SHIFT IN 1975 MEAN TOWARD DEGRADED PERFORMANCE	DISTRIBUTION OF 1967-1975 CHANGES SKEWED TOWARD DEGRADATION	
I_{IN}(1) (3-40)	✓	✓	✓		✓✓		NO MEASURABLE DRIFT
V_{OUT}(6-1) (3-41)				✓✓✓	✓✓✓	✓✓✓	PRONOUNCE DRIFT, VERY PRONOUNCED IN -σ PARTS
V_{OL}(6-1) (3-42)	✓	✓✓	✓	✓	✓✓	✓	NO MEASURABLE DRIFT IN +σ PARTS; SLIGHT DRIFT IN -σ PARTS
V_{OL}(7-1) (3-43)	✓	✓✓	✓	✓	✓✓	✓	NO MEASURABLE DRIFT IN +σ PARTS; SLIGHT DIRFT IN -σ PARTS
I_{RT} (3-44)	✓	✓	✓				NO SIGNIFICANT DRIFT
I_L(8) (3-45)	✓	✓	✓				NO SIGNIFICANT DRIFT
I_{CEX} (3-46)	✓	✓	✓				NO SIGNIFICANT DRIFT

*NOTE: CHECKS APPEARING IN FIRST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO NORMAL MEASUREMENT ERRORS; CHECKS IN LAST THREE COLUMNS SUPPORT CONCLUSION THAT DIFFERENCES ARE DUE TO PARAMETER DRIFT



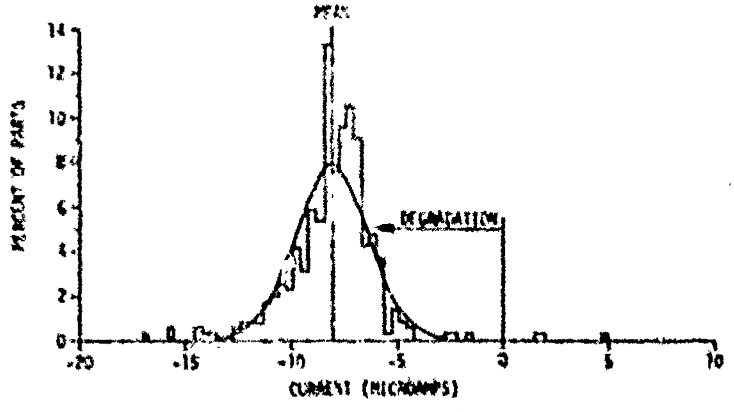
a. SCHEMATIC FOR I_{IN}(I) TEST (R_1 RESISTANCE + Q1 BASE EMITTER CHECK AT SATURATION VOLTAGE)



NO. OF PARTS REPRESENTED BY HISTOGRAM 350

TEST	MEAN	STD. DEV
1967	114.8μa	6.3μa
1975	122.9μa	6.5μa
1967-1975 DELTA	-8.11μa	1.76μa

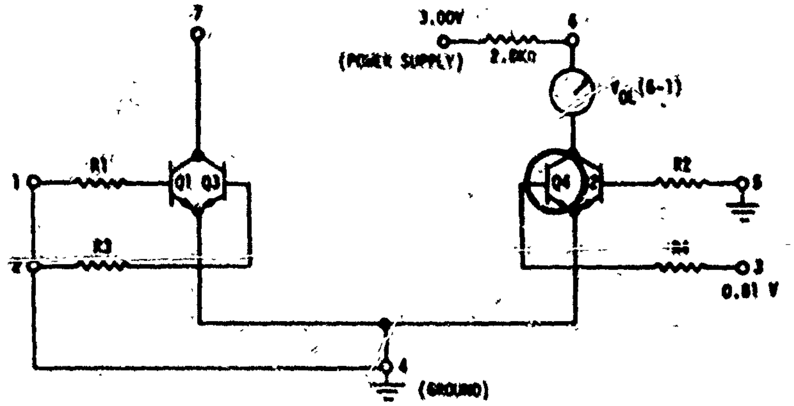
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



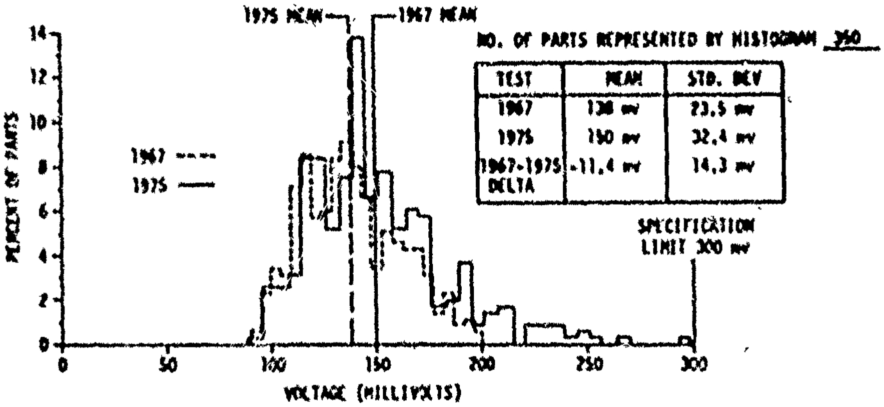
c. 1967 - 1975 CHANGE IN I_{IN}(I)

FIGURE 3-40. HISTOGRAM COMPARISON OF I_{IN}(I)

- EXPANDER -

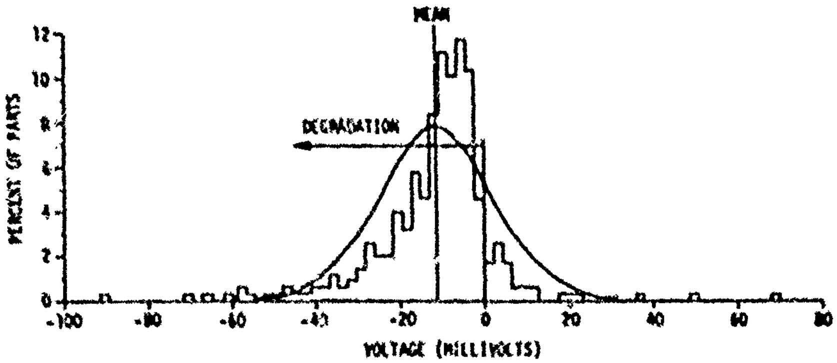


a. SCHEMATIC FOR V_{OUT}(6-1) TEST (Q4 VOLTAGE DROP AT MINIMUM "ON" CONDITION)



TEST	MEAN	STD. DEV
1967	138 mv	23.5 mv
1975	150 mv	32.4 mv
1967-1975 DELTA	-11.4 mv	14.3 mv

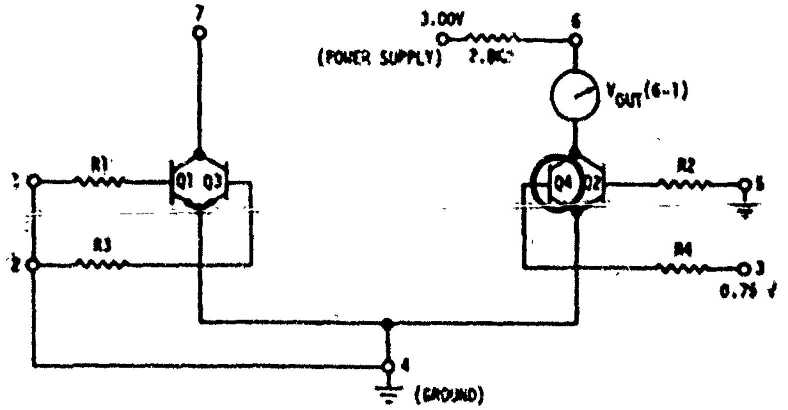
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



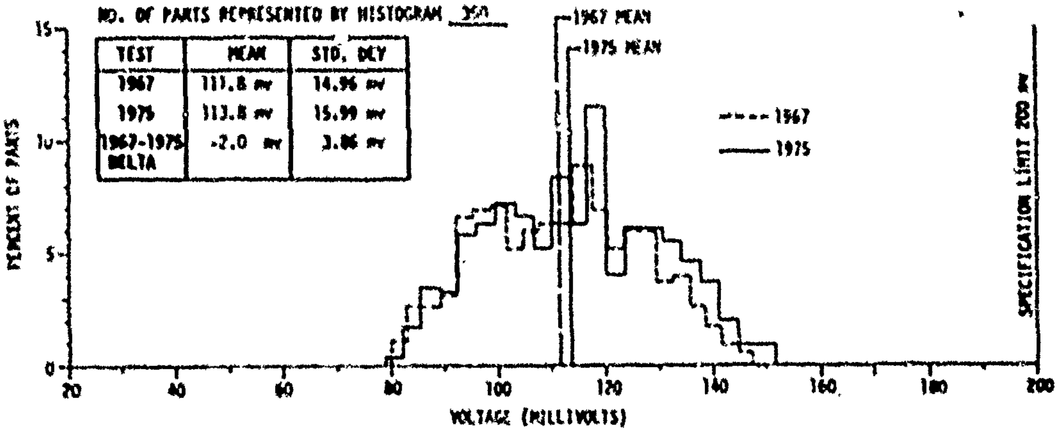
c. 1967 - 1975 CHANGE IN V_{OUT}(6-1)

FIGURE 3-41. HISTOGRAM COMPARISON OF V_{OUT}(6-1)

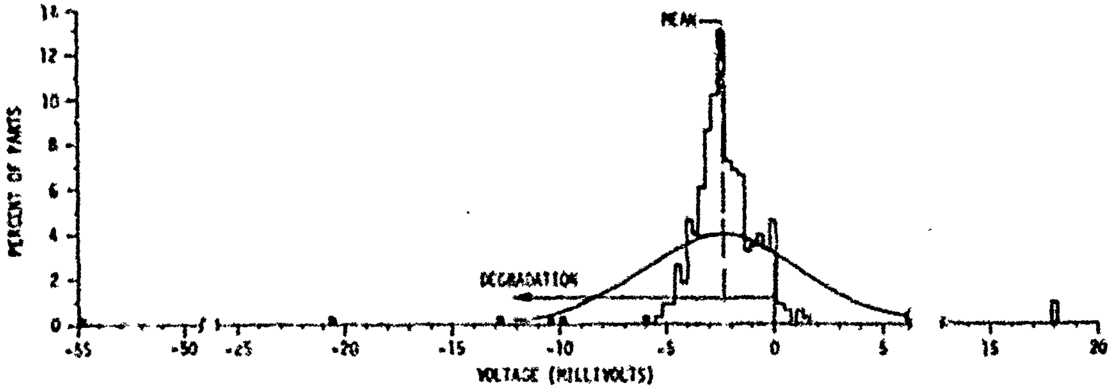
- EXPANDER -



a. SCHEMATIC FOR V_{OL}(6-1) TEST (Q4 VOLTAGE DROP AT SATURATION)



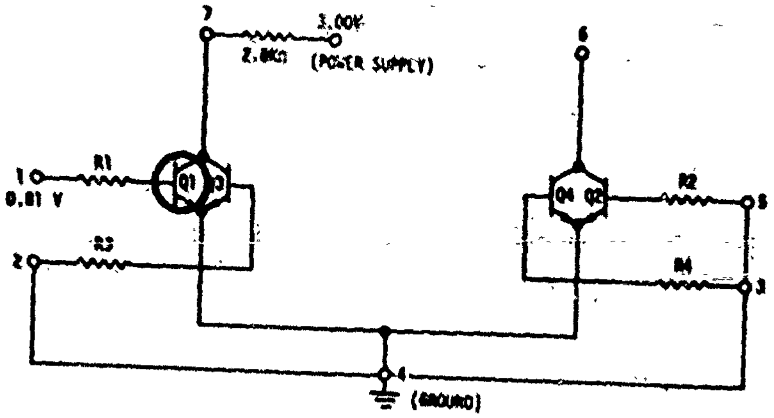
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



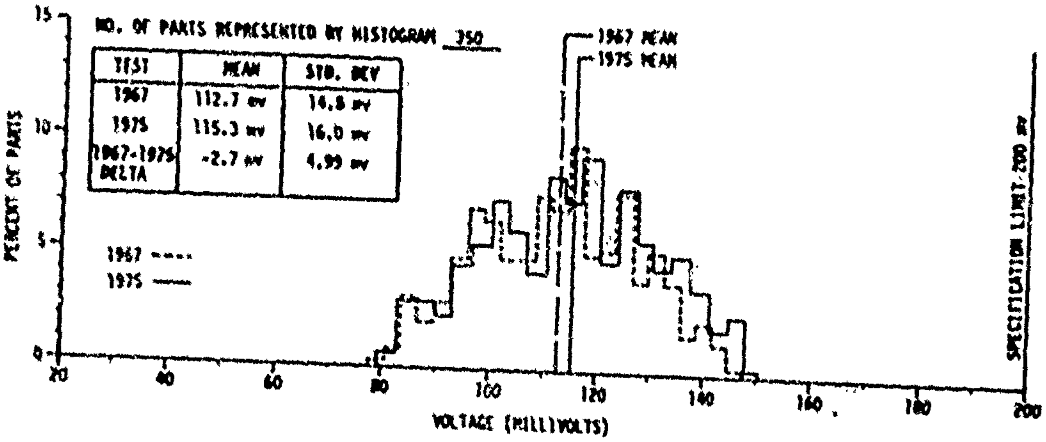
c. 1967 - 1975 CHANGE IN V_{OL}(6-1)

FIGURE 3-42. HISTOGRAM COMPARISON OF V_{OL}(6-1)

- EXPANDER -

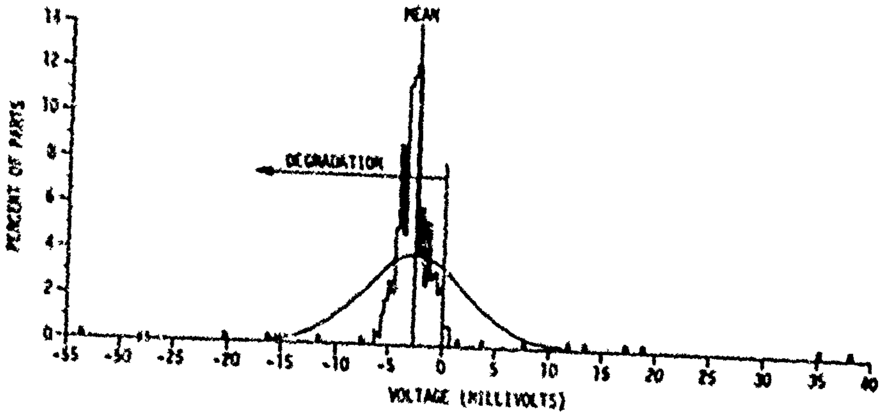


a. SCHEMATIC FOR V_{OL} (7-1) TEST (Q1 VOLTAGE DROP AT SATURATION)



TEST	MEAN	STD. DEV
1967	112.7 mv	14.8 mv
1975	115.3 mv	16.0 mv
1967-1975 DELTA	-2.7 mv	4.99 mv

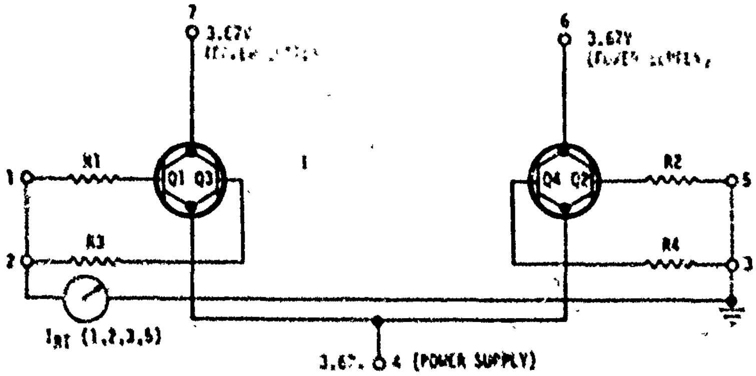
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



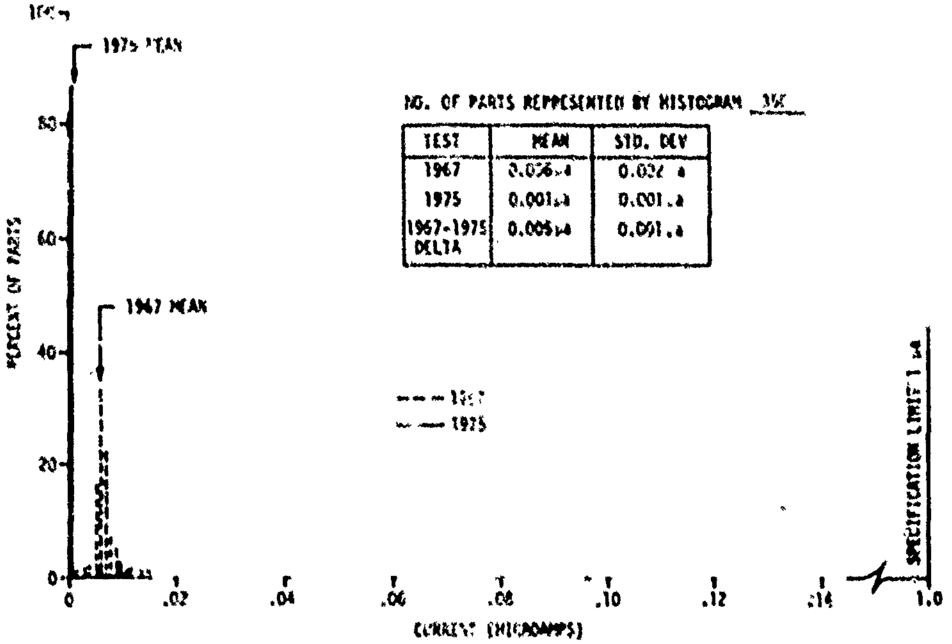
c. 1967 - 1975 CHANGE IN V_{OL} (7-1)

FIGURE 3-43. HISTOGRAM COMPARISON OF V_{OL} (7-1)

- EXPANDER -



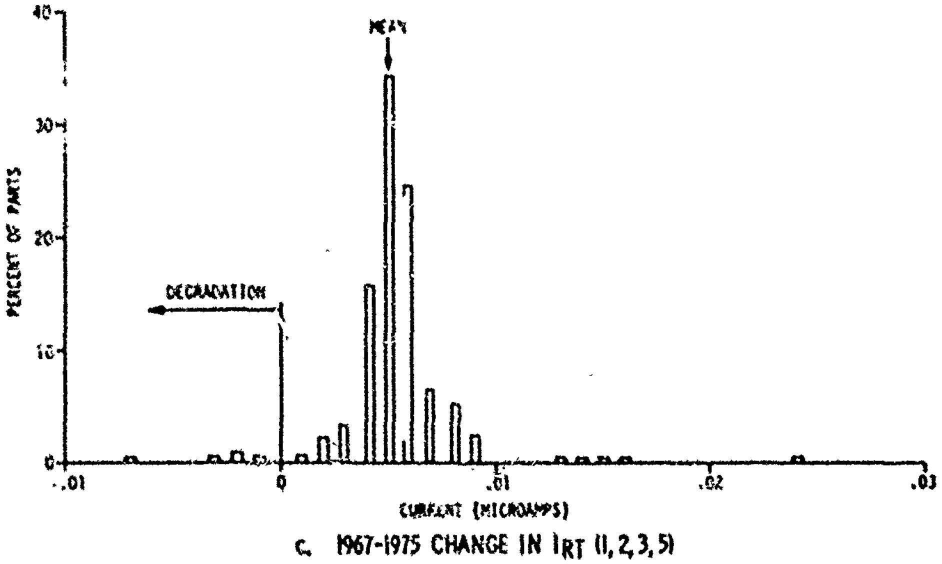
a. SCHEMATIC FOR I_{RT}(1, 2, 3, 5) TEST (Q1+Q2+Q3+Q4 BASE EMITTER JUNCTION LEAKAGE CURRENT)



NO. OF PARTS REPRESENTED BY HISTOGRAM 356

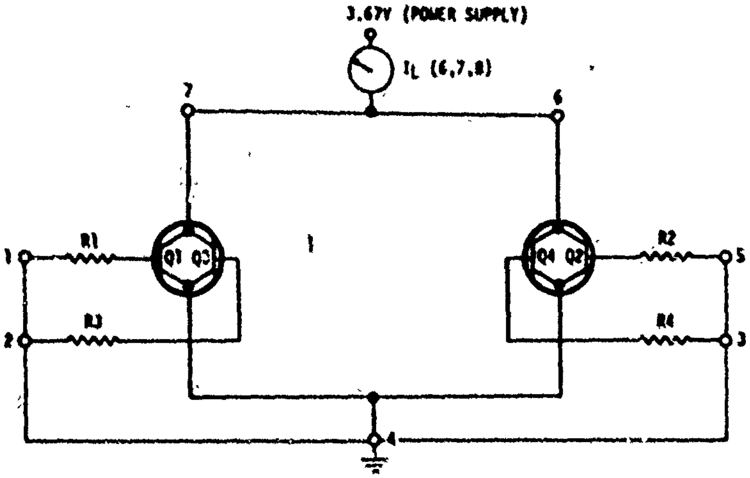
TEST	MEAN	STD. DEV
1967	0.006μA	0.002 μA
1975	0.001μA	0.001 μA
1967-1975 DELTA	0.005μA	0.001 μA

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST

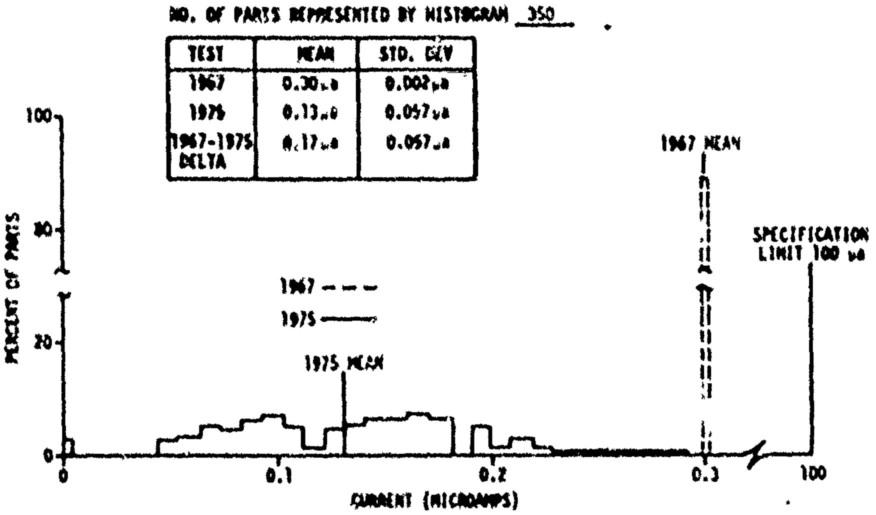


c. 1967-1975 CHANGE IN I_{RT} (1, 2, 3, 5)

FIGURE 3-44. HISTOGRAM COMPARISON OF I_{RT} (1, 2, 3, 5) EXPANDER

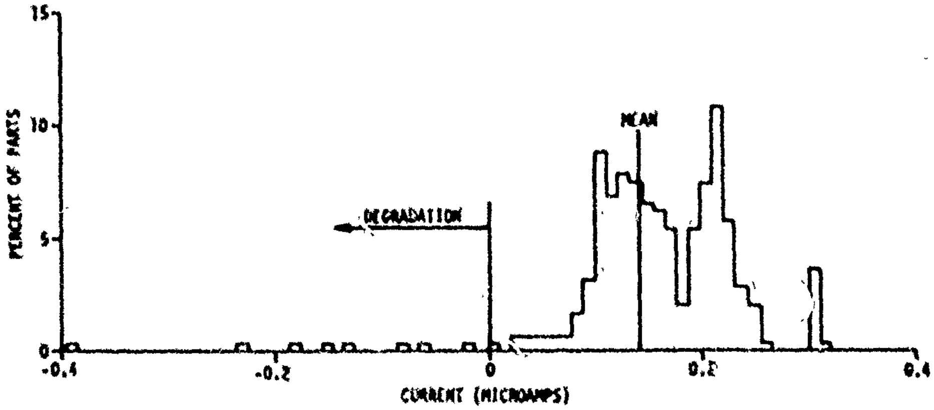


a. SCHEMATIC FOR I_L(6,7,8) TEST (Q1+Q2+Q3+Q4 LEAKAGE CURRENT AT MAXIMUM POWER SUPPLY VOLTAGE)


NO. OF PARTS REPRESENTED BY HISTOGRAM 350

TEST	MEAN	STD. DEV
1967	0.30 μa	0.002 μa
1975	0.13 μa	0.057 μa
1967-1975 DELTA	0.17 μa	0.057 μa

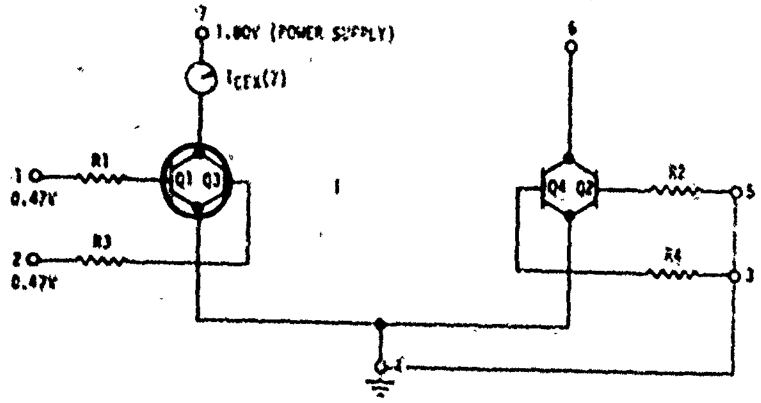
b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



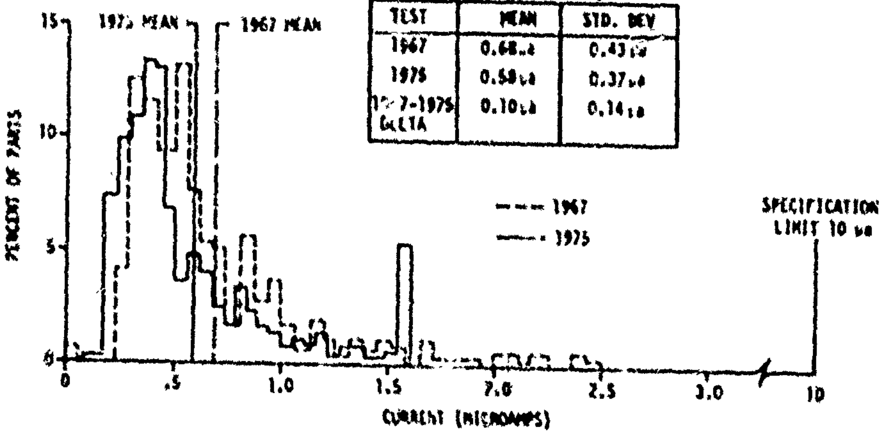
c. 1967-1975 CHANGE IN I_L

FIGURE 3-45. HISTOGRAM COMPARISON OF I_L

EXPANDER



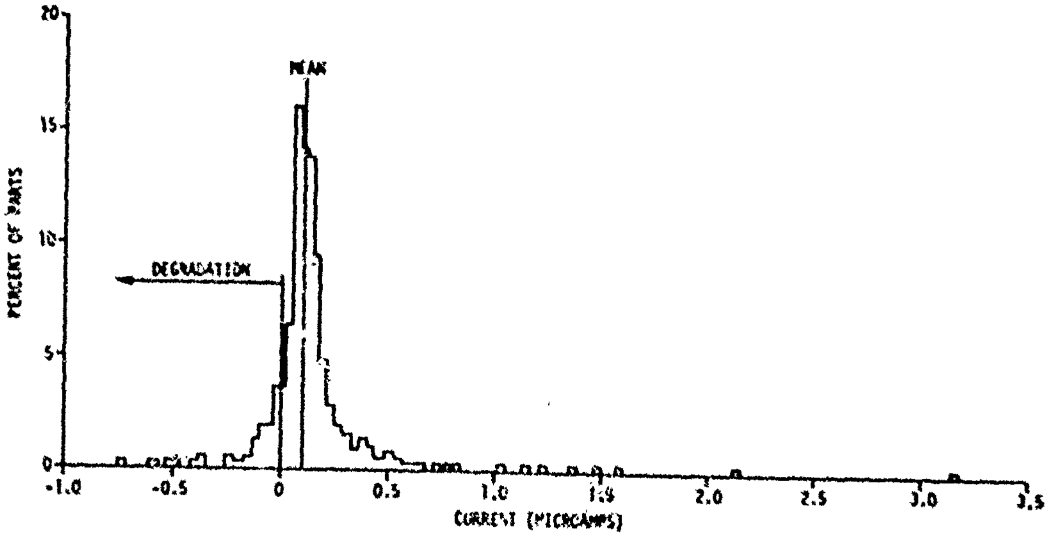
a. SCHEMATIC FOR $I_{CEX}(7)$ TEST (Q1+Q3 LEAKAGE CURRENT AT MAXIMUM "OFF" VOLTAGE)



NO. OF PARTS REPRESENTED BY HISTOGRAM 3[illegible]

TEST	MEAN	STD. DEV
1967	0.68μa	0.43μa
1975	0.58μa	0.37μa
1967-1975 DELTA	0.10μa	0.14μa

b. DISTRIBUTION OF PARTS: 1975 VS 1967 TEST



c. 1967-1975 CHANGE IN I_{CEX}

FIGURE 3-46. HISTOGRAM COMPARISON OF I_{CEX}

EXPANDER

SECTION 4

PRODUCT IMPROVEMENT GUIDELINES

4.0 PRODUCT IMPROVEMENT GUIDELINES

The results of this test program have been assessed to establish guidelines for increasing storage life. Recommendations are summarized in Table 4-I.

TABLE 4-I. PRODUCT IMPROVEMENT RECOMMENDATIONS

POTENTIAL FAILURES	TEST RESULTS	RECOMMENDATIONS
CATASTROPHIC		
BOND WIRE FAILURES PACKAGE PROBLEMS LEAD CORROSION/BREAKAGE	NO FAILURES NO FAILURES NO FAILURES	STORAGE INTEGRITY OF BOND WIRES, PACKAGES AND LEADS CAN BE ADEQUATELY ASSURED VIA THE FOLLOWING MILITARY SPECIFICATIONS AND STANDARDS FOR HI-REL PARTS: • MIL-STD-202, "TEST METHODS FOR ELECTRONIC AND ELECTRICAL COMPONENT PARTS • MIL-S-19500, "MILITARY SPECIFICATIONS, SEMI CONDUCTOR DEVICES GENERAL SPECIFICATIONS FOR" • MIL-G-45204, "GOLD PLATING, ELECTRODEPOSITED" • QQ-S-571, "SOLDER; TIN ALLOY, LEAD-TIN ALLOY, LEAD ALLOY"
OXIDE DEFECTS	3 FAILURES: FAILURE RATE = 0.0095 x 10^{-6} FAILURES/PART HR (90% CONFIDENCE LEVEL)	STORAGE INDUCED OXIDE DEFECT FAILURES CAN BE ADEQUATELY CONTROLLED VIA THE ABOVE SPECIFICATIONS/STANDARDS PLUS THE REQUIREMENTS THAT THOROUGH FUNCTIONAL TESTS BE PERFORMED AT THE CIRCUIT CARD LEVEL.
PARAMETER DRIFT		
RESISTANCE TRANSISTOR LEAKAGE	NO SIGNIFICANT DRIFT NO SIGNIFICANT DRIFT	ASSURE COMPLIANCE WITH THE SPECIFICATIONS AND STANDARDS CITED ABOVE
TRANSISTOR GAIN	SIGNIFICANT DRIFT	PERFORM "WORST CASE" CIRCUIT ANALYSIS TO DEFINE OPERATING RANGE OF EACH GAIN-DEPENDENT PARAMETER. ESTABLISH DESIGN SPECIFICATIONS AND/OR SCREENING TEST CRITERIA TO MAINTAIN ALL PARAMETERS WITHIN RELATIVELY LINEAR OPERATING RANGE ASSUMING A 30% LOSS IN GAIN (i.e., AVOID DRIFTING INTO REGIONS CHARACTERIZED BY THE STEEP PART OF FIGURE 4-1, WHERE A SMALL LOSS IN GAIN CAN CAUSE A LARGE CHANGE IN A CRITICAL PARAMETER).

The parts were packaged, assembled, inspected and tested to Boeing specifications that closely followed the Military Standards and Specifications cited in Table 4-I. There were no bond wire failures, no package problems, and no lead corrosion/breakage after eight years of storage; the cited specifications provide adequate storage reliability for these potential

4.0 (Continued)

failures modes. The only source of storage-induced catastrophic failures in these parts - oxide defects - can be controlled in a hardware system. Minuteman experience has shown that most of the latent oxide defects that survive part level burn-in can be detected and eliminated by assuring that adequate functional tests are performed at the circuit card level.

Parameter drift proved negligible in the resistance and transistor leakage characteristics. Transistor gain was the only parameter that exhibited a significant loss of performance during the eight years of storage. This is the one parameter that may have to be controlled to obtain a 10-20 year shelf life on these RTL devices. Transistor gain was not measured directly. However, the transfer function relating V_{OUT} to transistor gain was obtained from a special test of the Double Gate devices. The result is shown in Figure 4-1. Using this transfer function, and measured changes of V_{OUT}, hand calculations were made of the gain changes in 20 of the parts. These parts included all of the Double Gate incipient failures plus other parts selected randomly from the -1σ tail of the 1967 distribution. These parts showed reduction in gain ranging from 7 to 26%, with an average change of 13%.

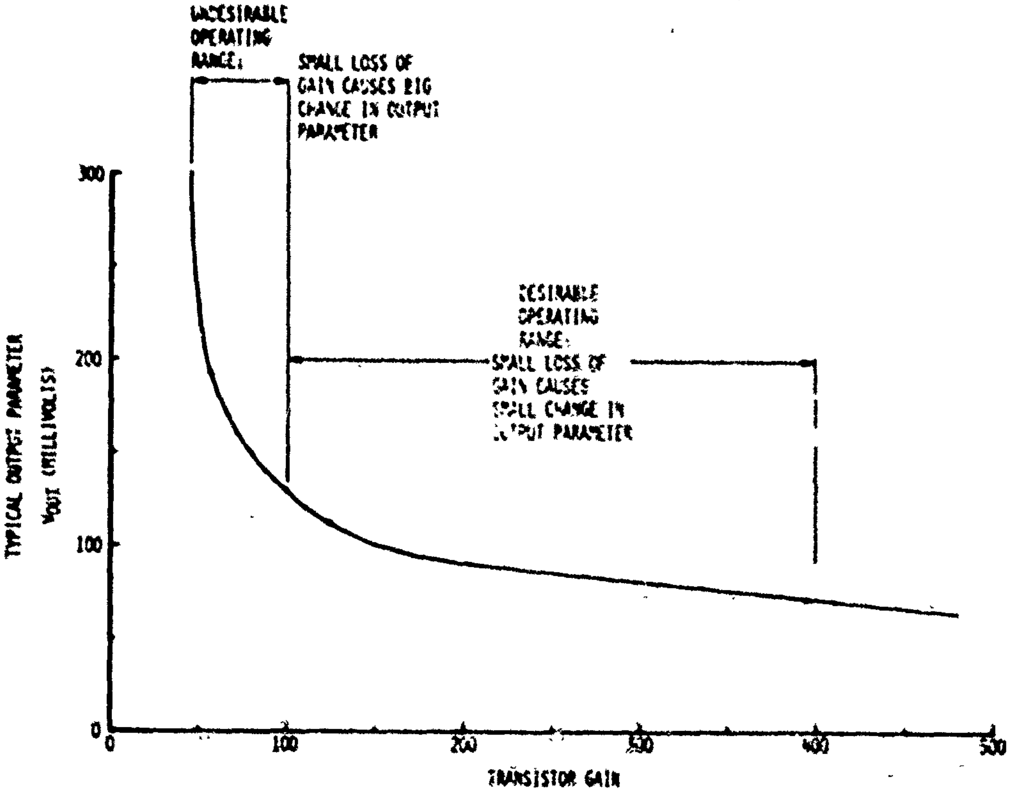


FIGURE 4-1. TYPICAL OUTPUT PARAMETER VS TRANSISTOR GAIN

4.0 (Continued)

To achieve long shelf life, the design specifications for new parts, or the screening test specifications for existing parts, should prevent operating the part in a highly non-linear region such as shown in Figure 4-1.

If a new part is being developed, the diffusion profiles can be adjusted to obtain higher gain parts in which a small loss of gain does not cause a large degradation in one of the output parameters. Screening tests can also be used to reject the lower gain parts which could lead to the output parameter(s) drifting into the non-linear region. The circuit card designer can also limit fanout (the number of inputs driven by a single output) to less than the Manufacturer's rating to prevent operating on the steep part of the output-gain curve. The following approach is recommended to achieve adequate control of transistor gain drift during storage:

1) Perform analysis of design to determine worst case operating regions.

2) Determine the part gain and/or circuit card fanout limits required to keep the output parameters from drifting into the highly non-linear operating region assuming a 30% loss of gain (10 yr shelf life).

3) Establish design and/or screening test criteria to accomplish (2) above.

The screening tests could be imposed at the wafer level. Wafers that would yield high gain parts would be selected for long storage life applications, with the remainder going to commercial use.

As previously stated, rejecting the 16% (-1σ) of the parts with the highest V_{OUT} measurements (lowest gain measurements) would have eliminated all but one of the incipient parameter drift failures. A worst case analysis of the Minuteman logic circuits was performed to evaluate the effect of V_{OUT} drifting above the 300 mv specification. The analysis showed that these parts would still reliably perform their logic functions even when degraded well beyond the 300 mv limit. Consequently, these particular parts are deemed to have adequate storage life reliability without imposing more severe test criteria. However, other devices may be more dependent on the gain of their transistors and should be evaluated on a case-by-case basis.

4.1 TRANSISTOR GAIN DRIFT MECHANISMS

The shelf-life drift observed in transistor gain is attributed to one or a combination of the following mechanisms:

1) Changes in the gold doping process, which is used to control the "parasitic transistor" condition*, as well as to increase part switching speed.

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*Refer to pp 222-226, Fundamentals of Silicon Integrated Device Technology, Vol. II, Edited by R. M. Burger and R. P. Donovan, Prentice-Hall, 1968, for an explanation of the "parasitic transistor" condition.

4.1 (Continued)

2) Growth of a "parasitic transistor" condition due to migration of contaminants, or to changes in the gold doping process.

In devices of this type, a parasitic base-to-substrate transistor can form due to migration of contaminants or gold. This parasitic transistor shunts part of the base current around the base emitter junction, effectively reducing transistor gain. The gold may also migrate within the silicon lattice structure, thereby reducing the gain directly. Since all of the incipient failure parts were operating in the non-linear region characterized by Figure 4-1, small gain changes were able to produce large increases in the V_{OUT} parameter. Selected incipient failures are being provided to Georgia Institute of Technology, who will attempt to determine the physical changes that are causing the observed drift.