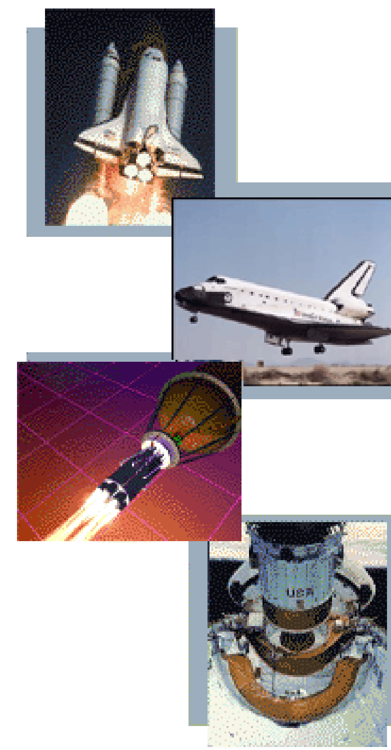
NASA Proprietary Material

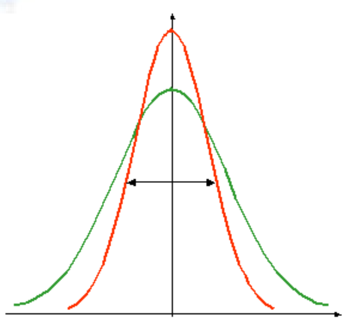
NASA Reliability/Quality Data Analysis

High Precision Voltage Reference Part Type



Preliminary Release for NASA Distribution Only

Commercial Off-The-Shelf Plastic Encapsulated Microcircuits Evaluation for NASA Space Requirements



NASA NEPP Task Number 100774 1.J.49.1

Contents:

Vendor A Burn-In Data
Reliability Analysis

"High Precision Voltage Reference"

Preliminary Data Released for NASA Distribution Only

The purpose of this test is to electrically and thermally stress the parts to identify/accelerate potential failure modes due to weak devices which can then be eliminated

Introduction

This reliability analysis includes three high temperature performance specifications, VRLDSI A, VRLDSI B, and SHUNT REG which showed significant degradation after a +125C burn-in preconditioning for 168 hrs. Other part parameters measured at high temperature showed acceptable performance and stability.

This report does not include failure analysis as to the root cause such as design, process, or assembly faults.

Various plots and graphs are shown that demonstrate reliability and data sheet electrical performance.

Reliability of a component is finding out the probability that the component will perform under it's intended operating conditions for a set period of time. A degradation failure has occurred if a parameter value drifts or degrades outside a pre-determined limit or an imposed performance application requirement(s).

ATE Electrical Test Conditions Used:

"LOAD REGULATION, SERIES MODE" and "LOAD REGULAION, SHUNT MODE" are listed below.

Series mode is tested with the input at 5.0 V. The difference in output voltage with 0 MA and 10 MA sink current is measured. The "A" test is at 2.5 V out. The "B" test is with 3.0 V out. Accuracy is +/- 200uV.

Shunt mode is tested with the input at 2.5 V. The difference in output voltage with 1 MA and 10 MA is measured.

For all tests the input is bypassed with 1 UF to ground.

DEFINING AN EFFECTIVE BURN-IN

If $F_b(t)$ = failure distribution (all failures) *before* burn-in

And $F_a(t)$ = failure distribution (all failures) *after* burn-in

And τ is the burn-in time

Then $F_a(t) = [F_b(t+\tau) - F_b(\tau)]/[1-F_b(\tau)]$

For burn-in to be *effective*, F_a must be superior to F_b

$$\lambda = \left(\frac{\gamma}{n \times t \times Kt \times Kv}\right) \times 1E9 \text{ [fit]}$$

$$Kt = \exp\left[\frac{Ea}{k}\left(\frac{1}{T1} - \frac{1}{T2}\right)\right]$$

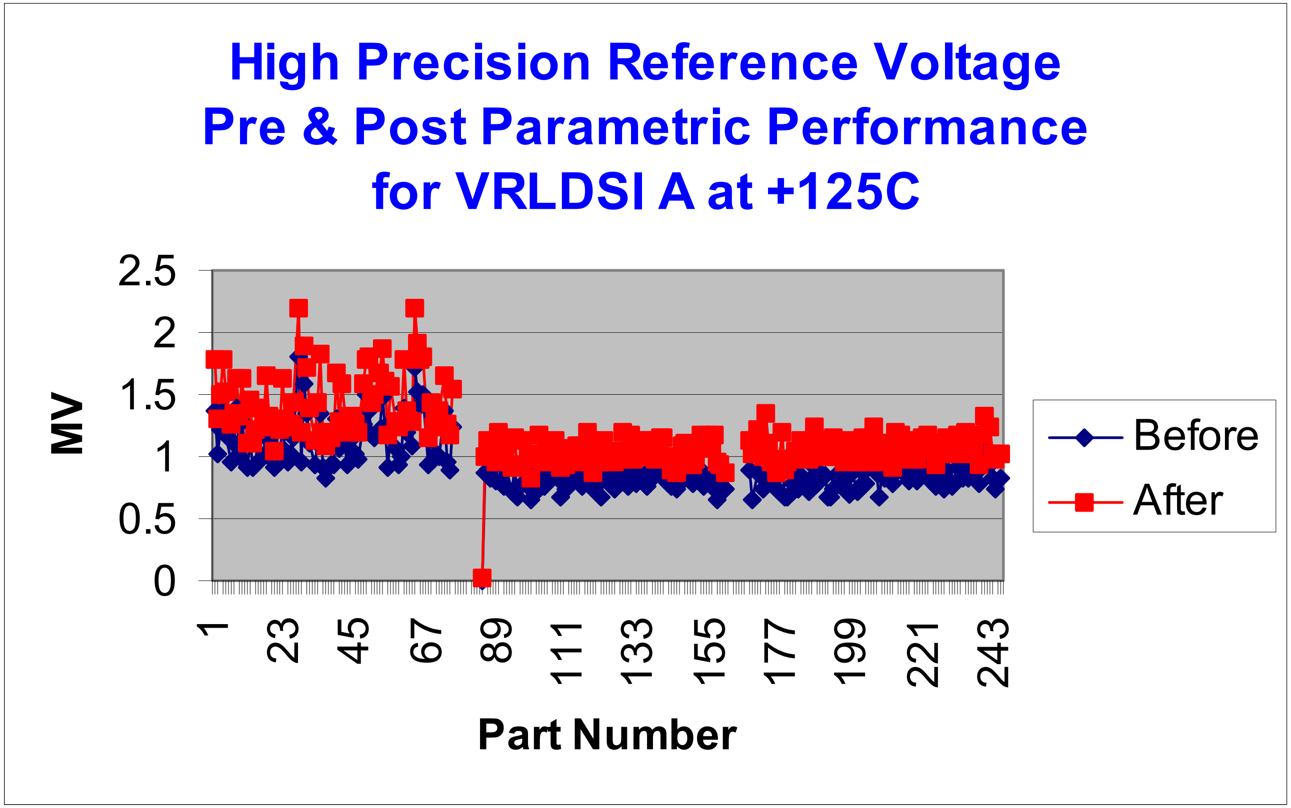
$$Kv = 10^{B\,(E2-E1)}$$

Table 1

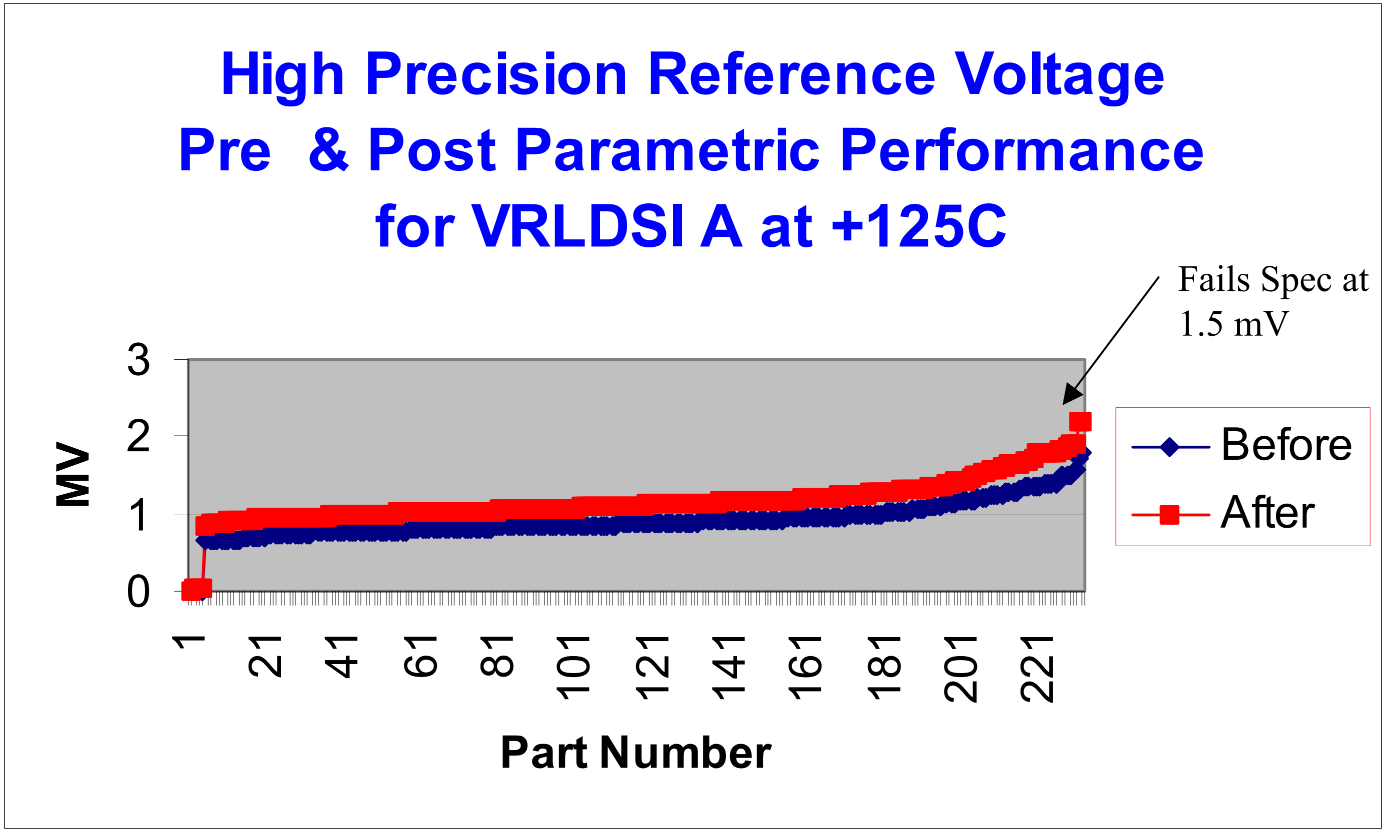
Number of Failures	0	1	2	3	4	5
Coefficient γ	0.92	2.02	3.11	4.18	5.24	6.29

λ: Failure rate
γ: Reliability coefficient (60% reliability level is used.) (See Table 1.)
n: Number of tests
t: Test time
Kt: Temperature acceleration coefficient
Ea: Activation energy
k: Boltzmann's constant (8.617E-5eV/K)
T1: Ambient temperature (absolute temperature)
T2: Test temperature (absolute temperature)
Kv: Voltage acceleration coefficient
B: Acceleration factor
E1: Electric field strength of oxide film at rated voltage (MV/cm)
E2: Electric field strength of oxide film during test (MV/cm)

Failure Rate Calculation

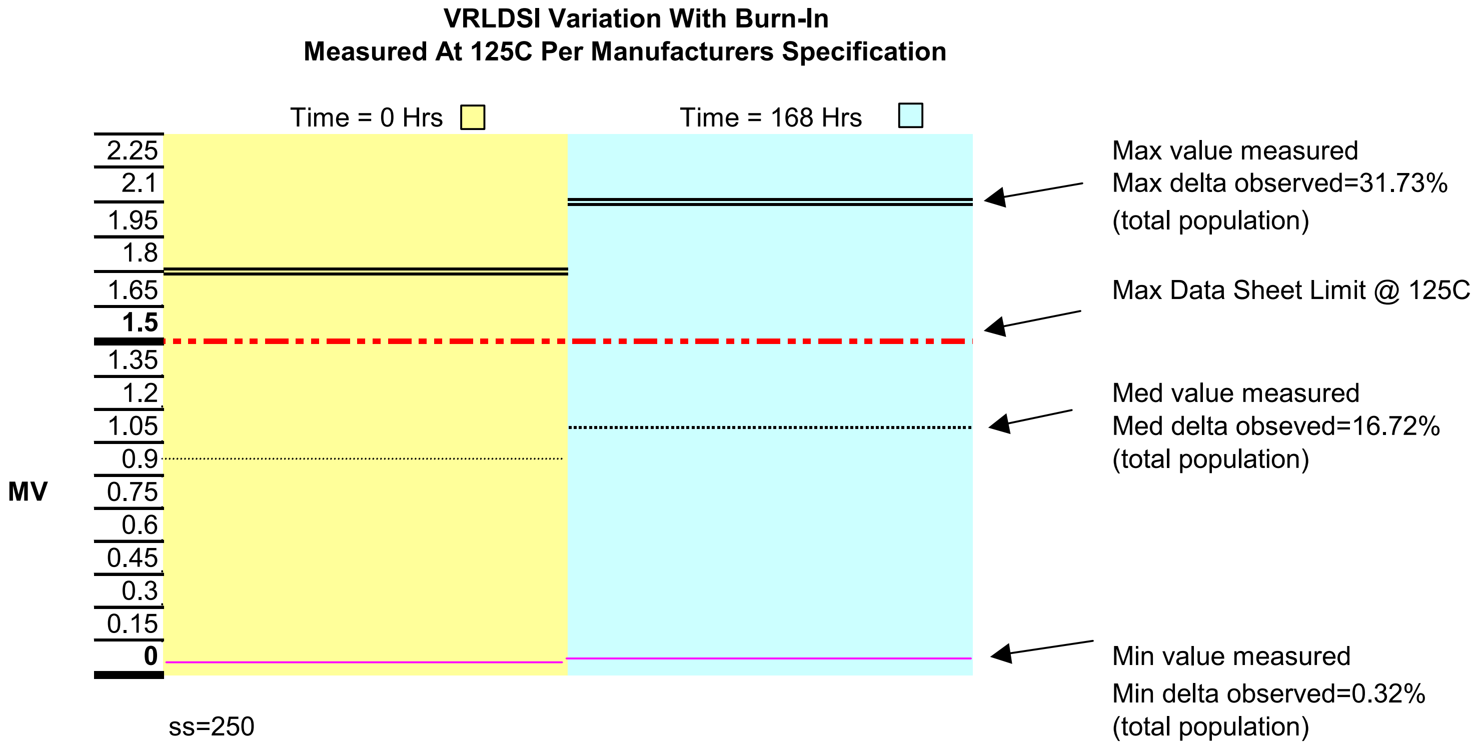


This plot demonstrates that the parameter Load Regulation Series Mode Sinking parameter has undergone a degradation in the performance after a +125C burn-in preconditioning. Parts vary in the amount of degradation. Three different date codes are included in the samples measured. Similar type results were found with parameters VRLDSI B and Shunt Regulation.



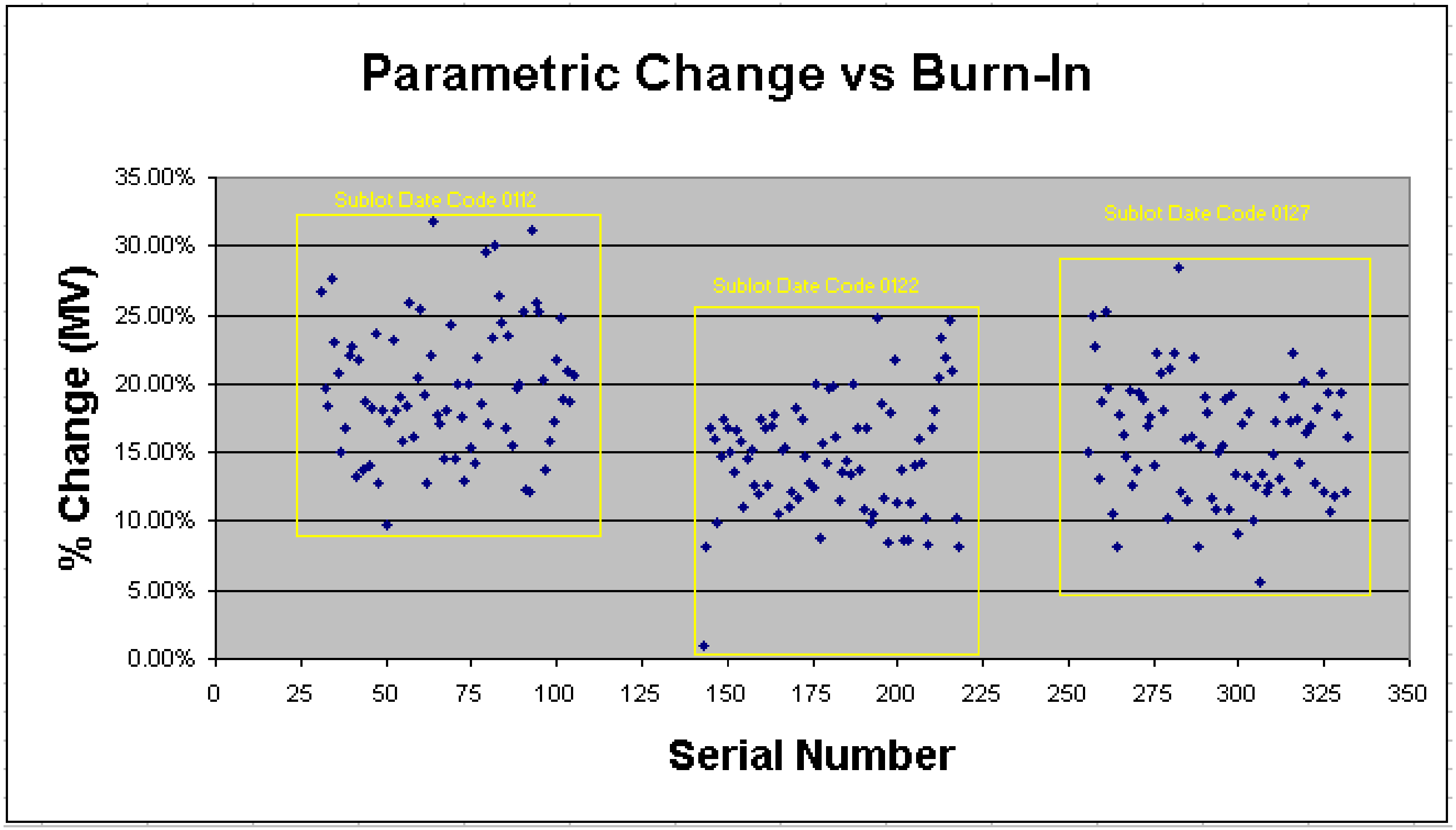
This plot demonstrates that the parameter Load Regulation - Series Mode Sinking parameter has undergone a degradation in the performance after a +125C burn-in preconditioning. Recorded values are sorted in ascending order. The number of parts failing the 1.5MV upper limit has increased after burn-in. Similar type results were found with parameters VRLDSI B and Shunt Regulation.

"High Precision Voltage Reference" Measured Performance vs Burn-In



"High Precision Voltage Reference" Measured Performance vs Burn-In

VRLDSI A @+125C



"High Precision Voltage Reference" Measured Performance vs Burn-In

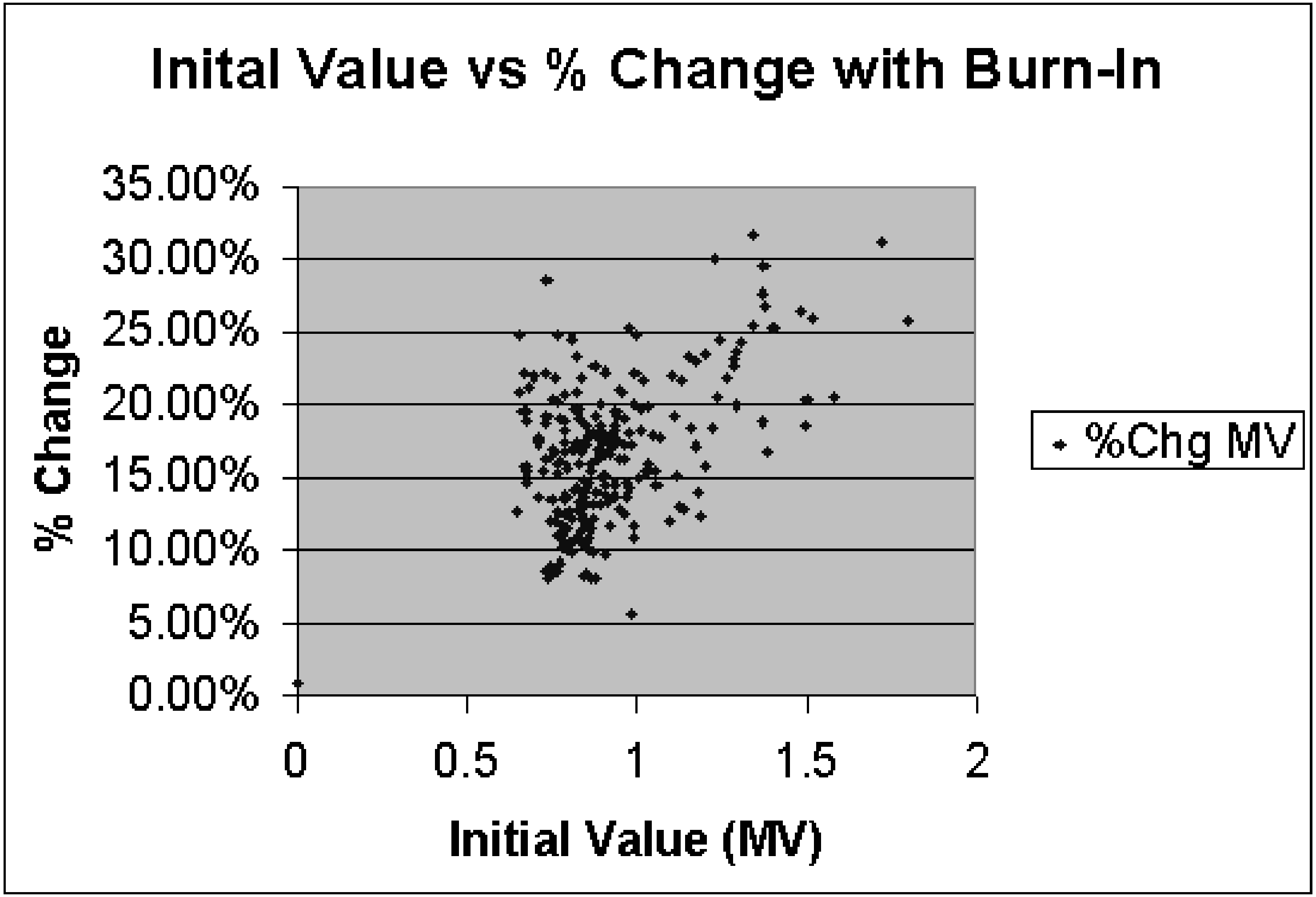
Statistical Results of the t-test between date codes 0112 and 0122:

	Variable 1	Variable 2
Mean	0.197402	0.146898
Variance	0.002336	0.001821
Observations	75	75
Pearson Correlation	0.112825	
Hypothesized Mean Difference	0	
df	74	
t Stat	7.19907	
P(T<=t) one-tail	2.09E-10	
t Critical one-tail	1.665708	
P(T<=t) two-tail	4.17E-10	
t Critical two-tail	1.992544	

These two date code are statistically different with a 95% confidence level!!

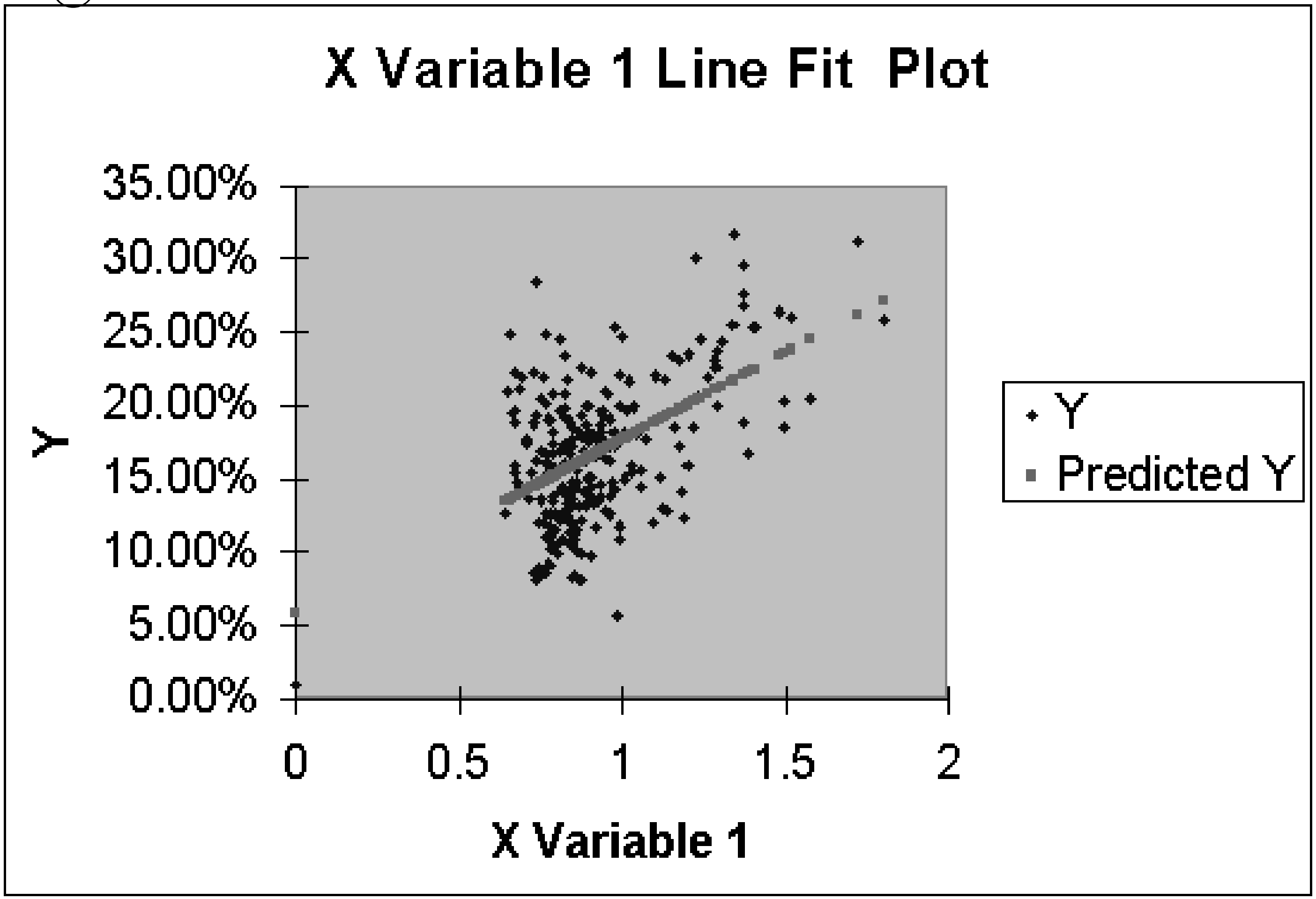
"High Precision Voltage Reference" Measured Performance vs Burn-In

VRLDSI A @+125C



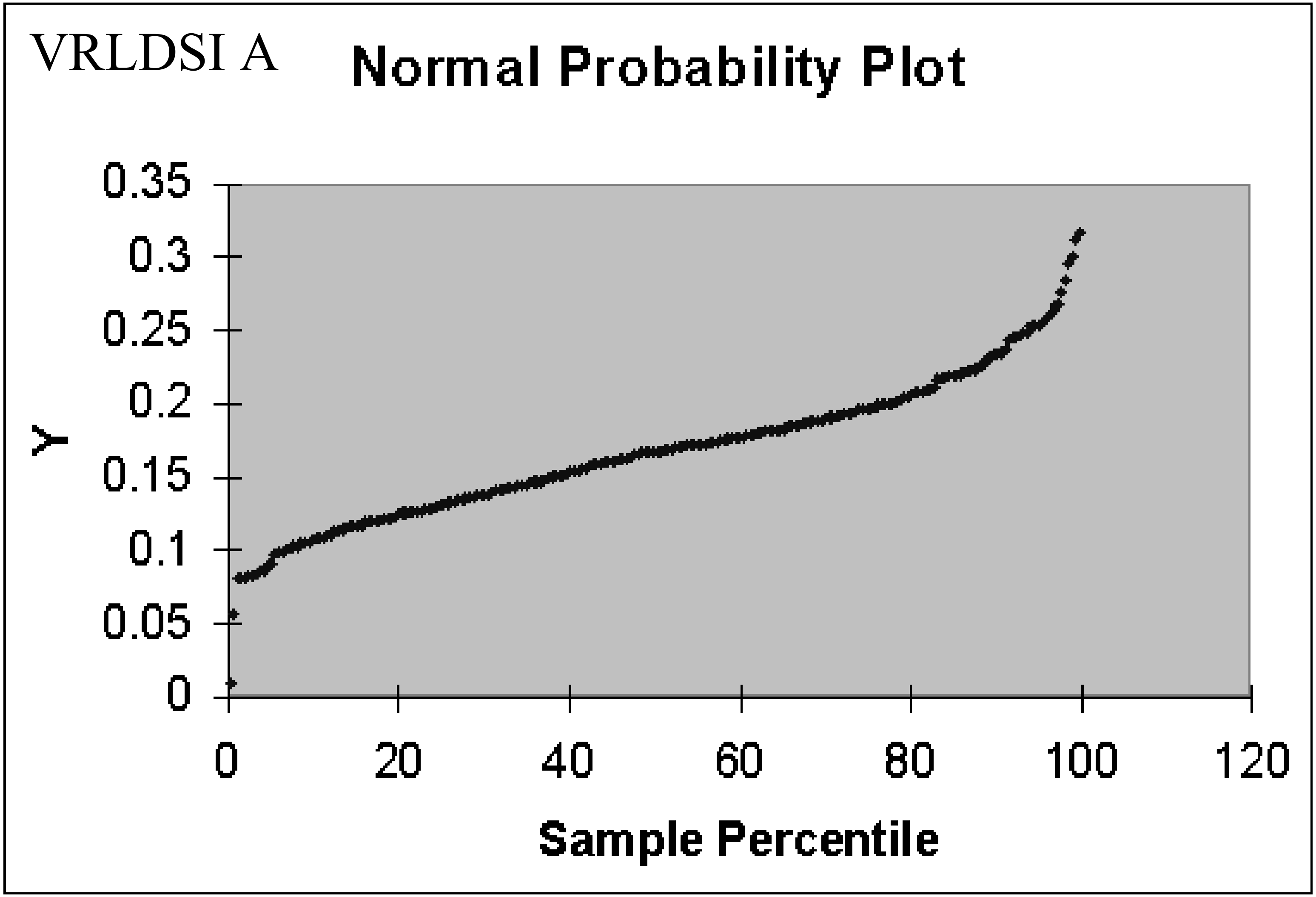
"High Precision Voltage Reference" Measured Performance vs Burn-In

VRLDSI A @+125C



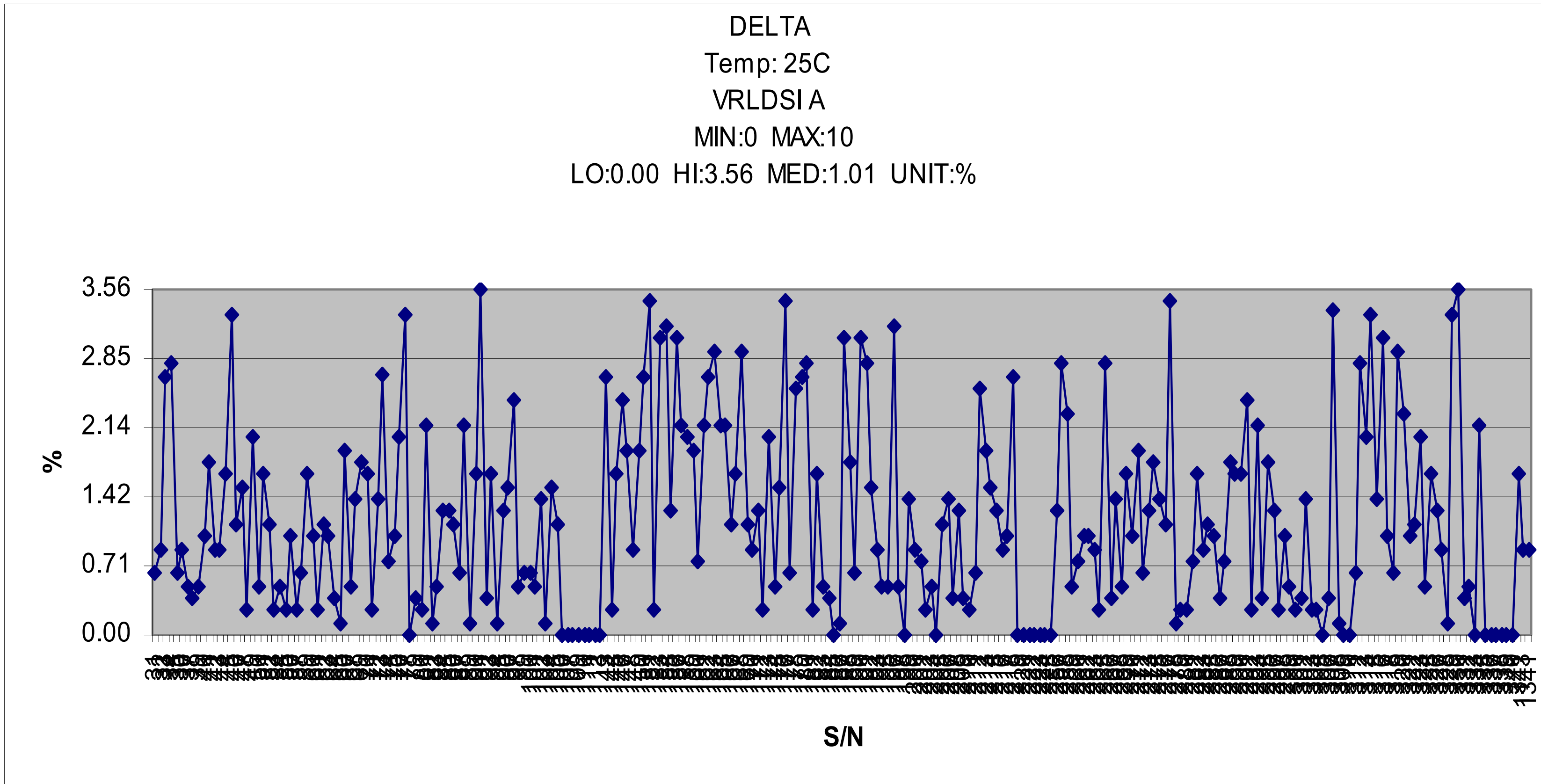
% Change(Y) vs Pre-Burn-In Value (X in MV) With Linear Regression Prediction

"High Precision Voltage Reference" Measured Performance vs Burn-In



"High Precision Voltage Reference" Measured Performance vs Burn-In

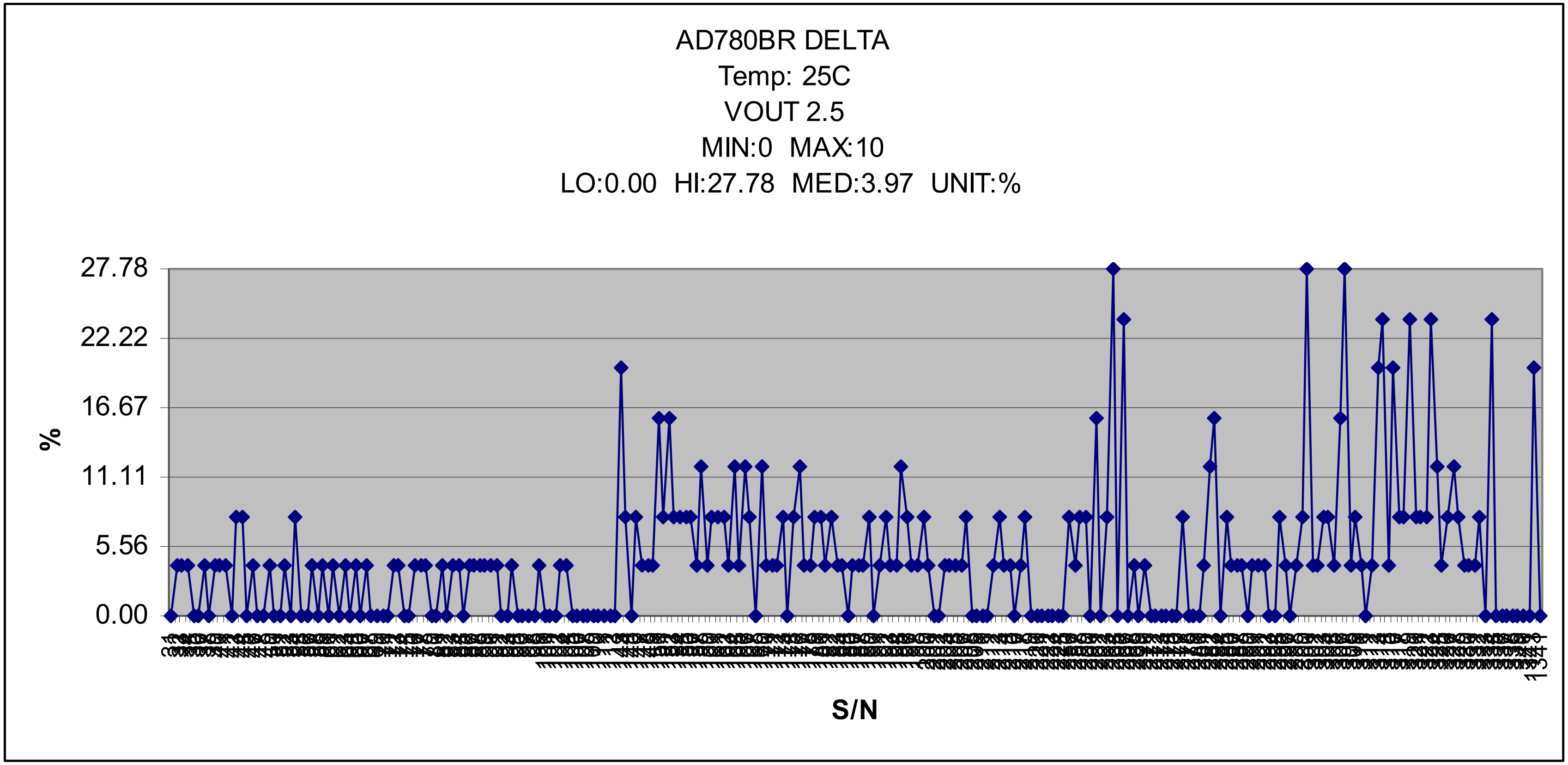
VRLDSI A Vout=2.5V@ 10ma Pre vs Post Burn-In @25C



All parts passed data sheet specification for this parameter.

"High Precision Voltage Reference" Measured Performance vs Burn-In

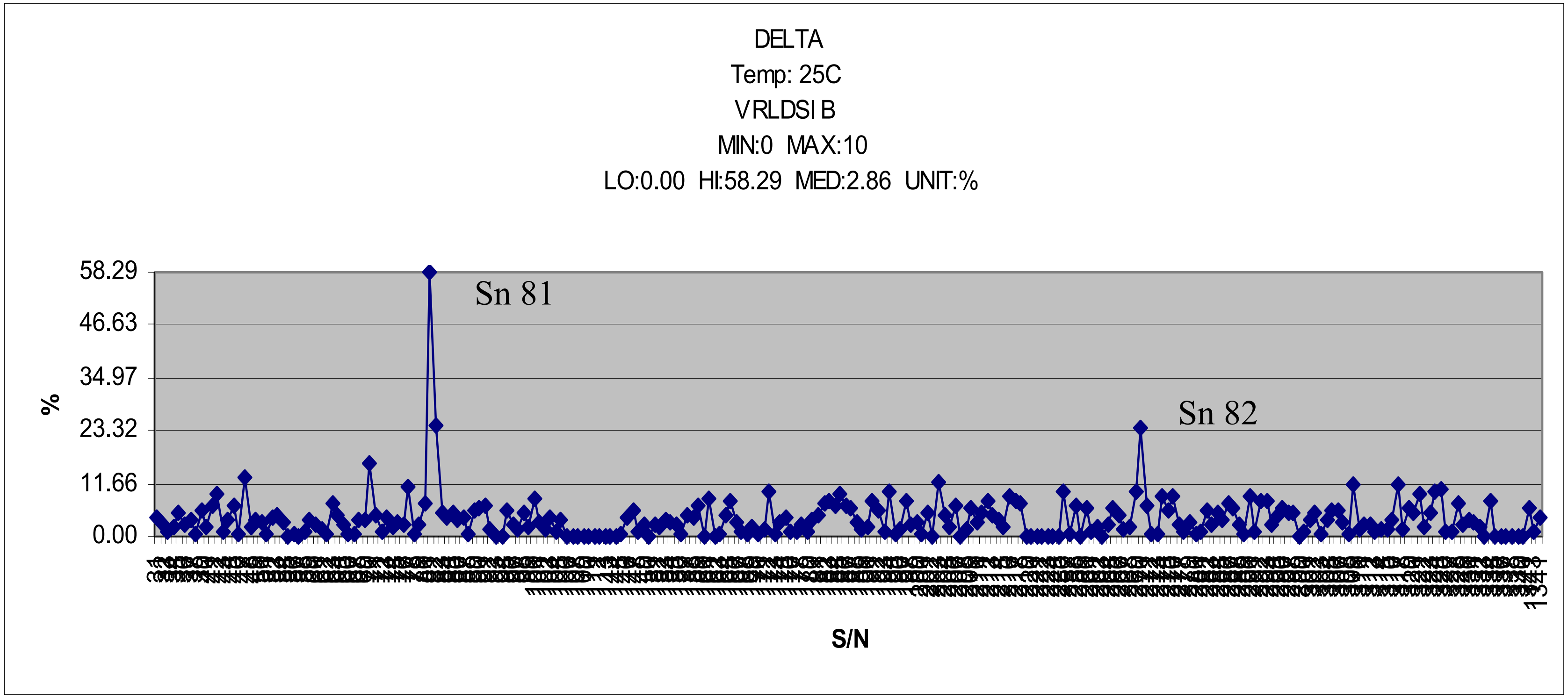
Vout=2.5V no load Pre vs Post Burn-In @25C



29 parts failed minimum data sheet specification for this parameter.

"High Precision Voltage Reference" Measured Performance vs Burn-In

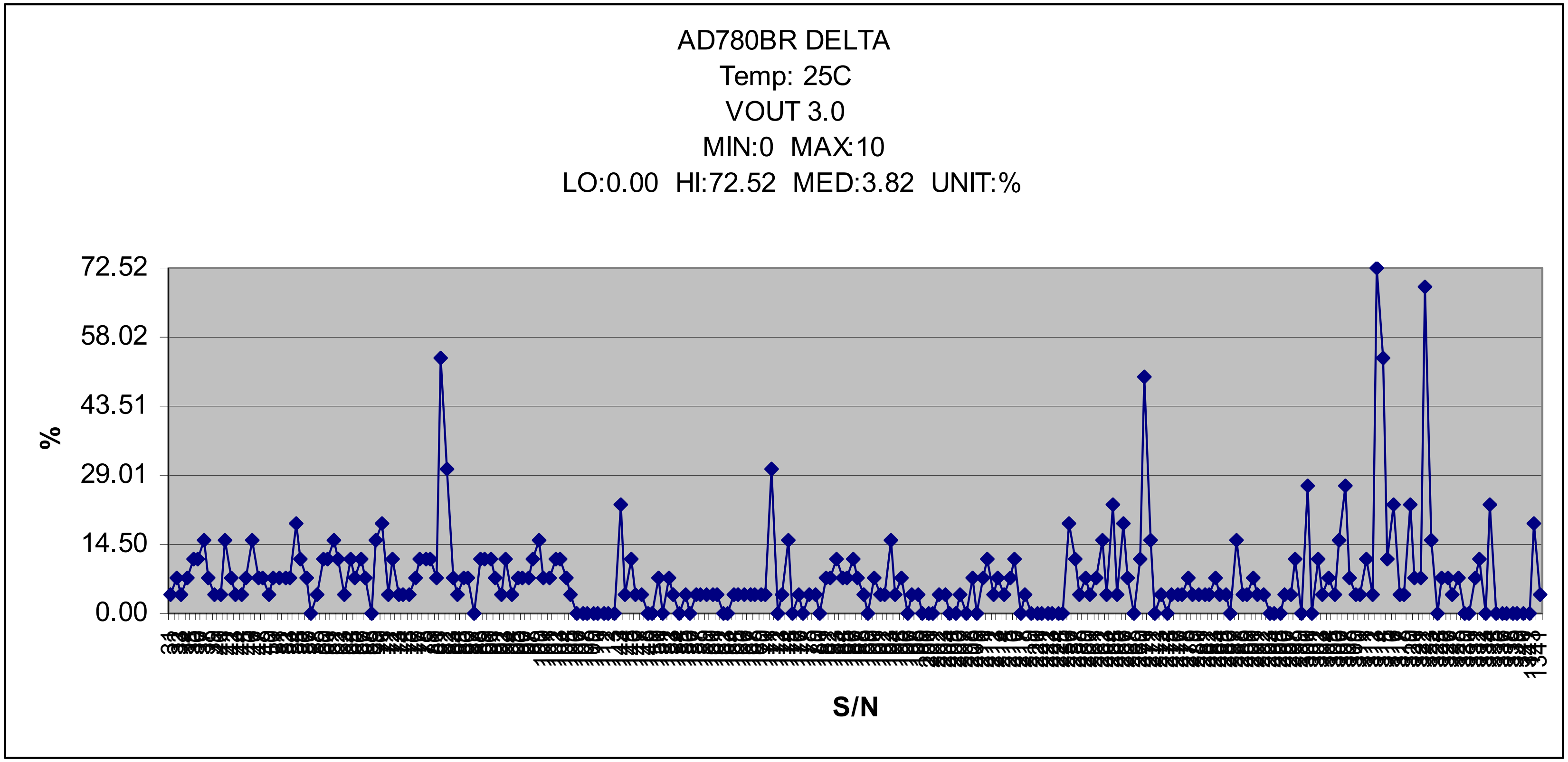
VRLDSI B Vout=3.0V @ 10 ma Pre vs Post Burn-In @25C



All parts passed data sheet specification for this parameter.

"High Precision Voltage Reference" Measured Performance vs Burn-In

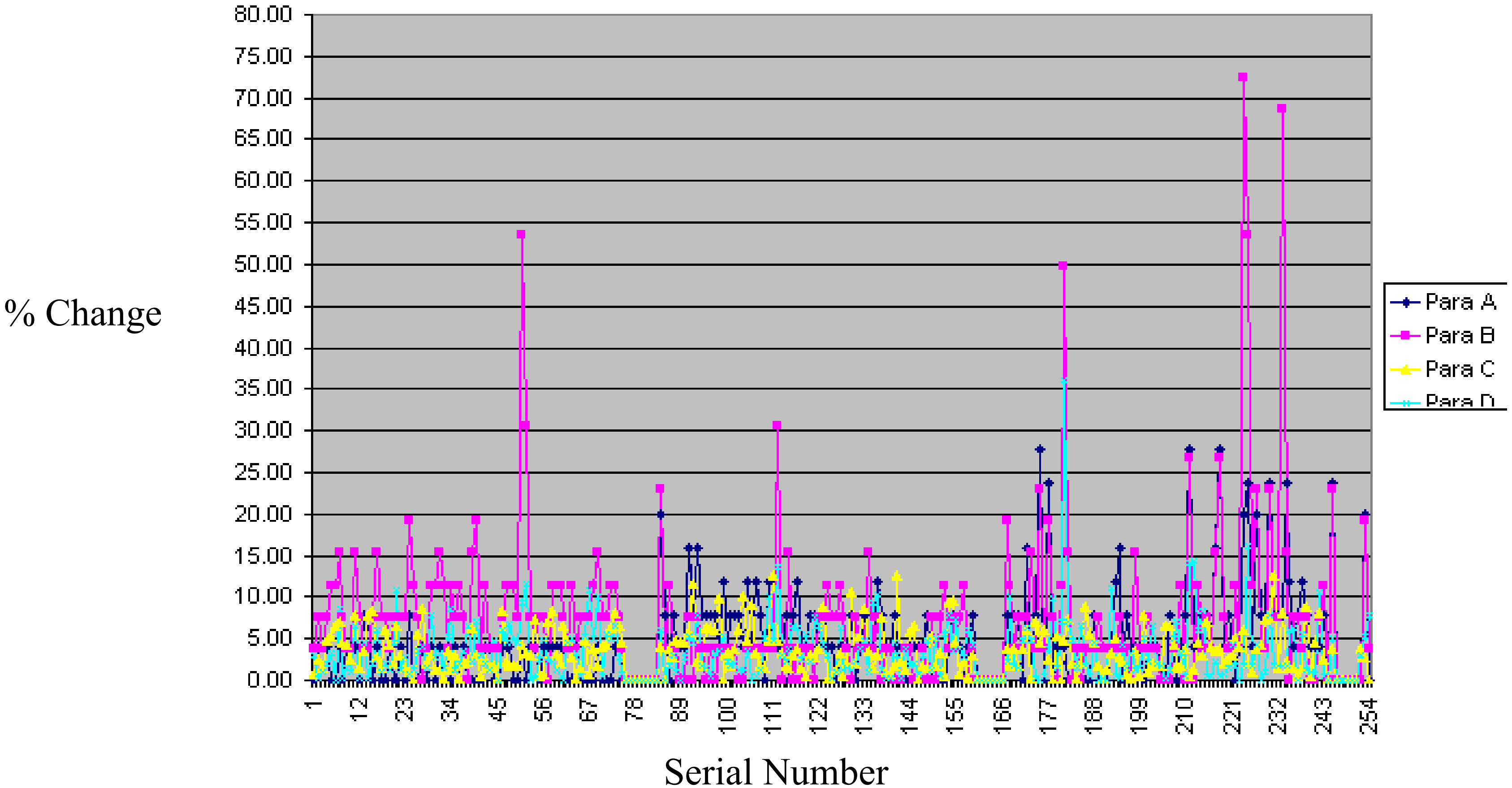
Vout=3.0V no load Pre vs Post Burn-In @25C



29 parts failed minimum data sheet specification for this parameter.

"High Precision Voltage Reference" Measured Performance vs Burn-In

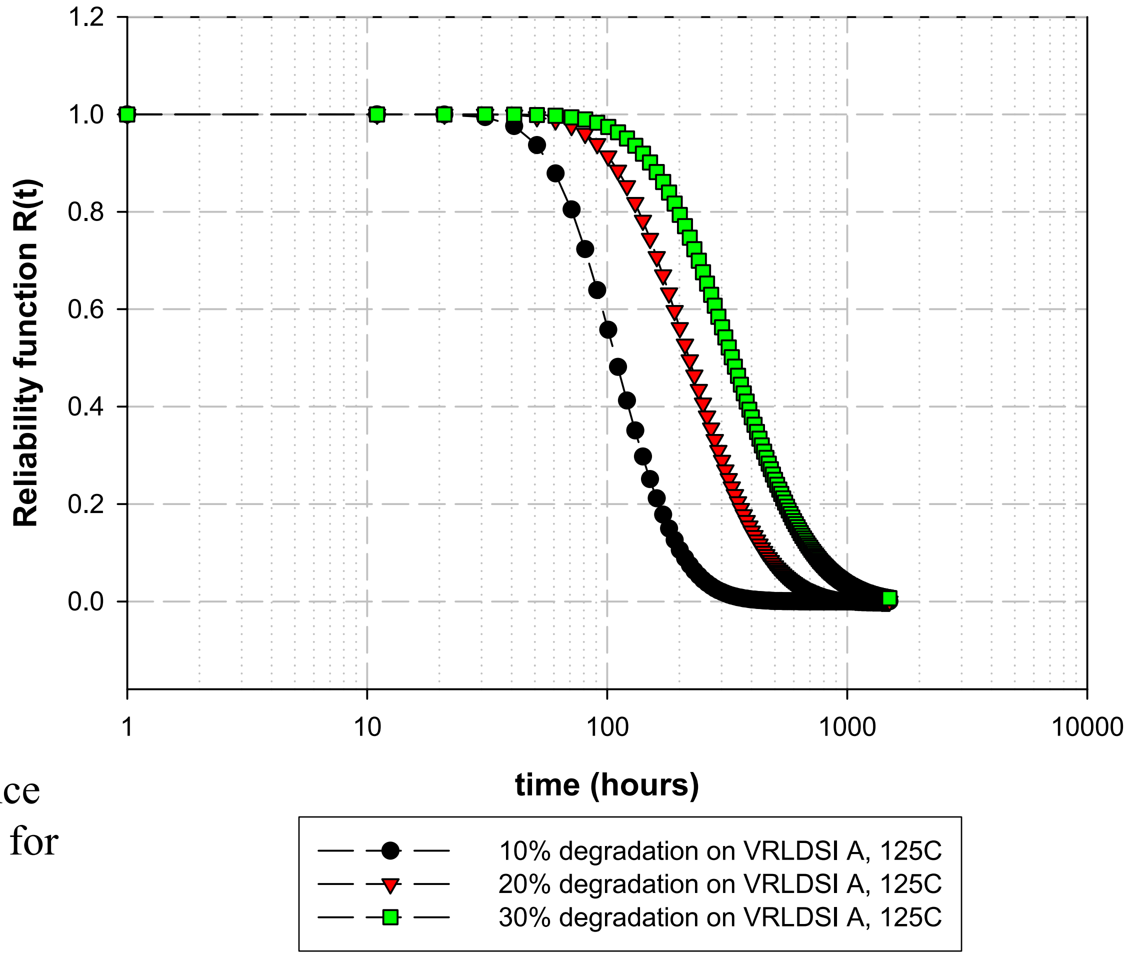
Examples of 4 Different Parameters by Serial Number That Showed More Than 10% Change with Burn-In (Parameters Were Measured at 25C).



Reliability Plot for High Precision Reference Voltage - VRLDSI A

Post BI High Temperature Reliability Performance vs Degradation

- COTS PEM
- ss = 250
- Single vendor
- BI precondition (time/temperature)



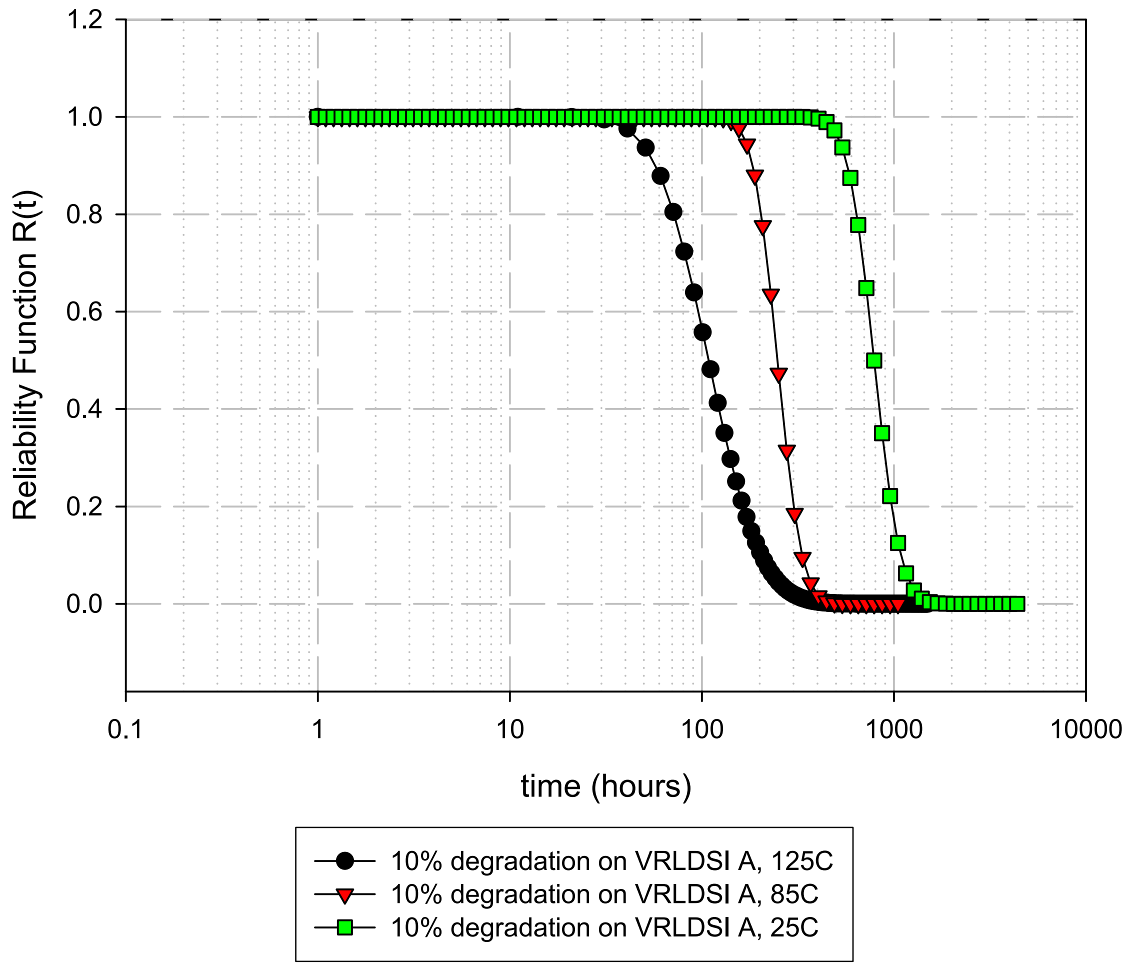
This plot demonstrates what reliability is expected with time depending on the % of performance degradation accepted by the user, for the intended application(s).

Reliability Plot for VRLDSI A at 125C, 85C and 25C

Post BI Temperature Reliability Performance vs 10% Degradation

- COTS PEM
- ss = 250
- Single vendor
- BI precondition (time/temperature)

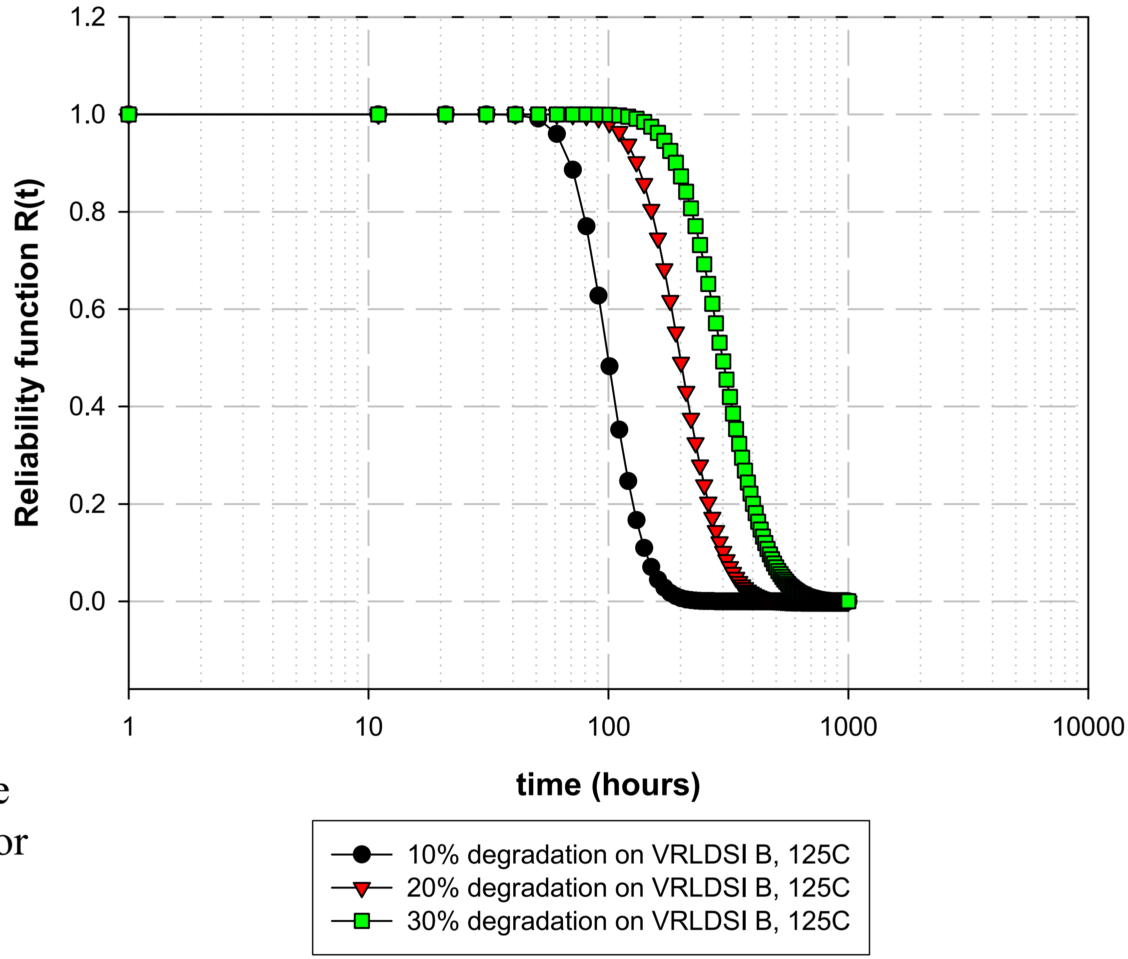
This plot demonstrates that better performance reliability can be expected at lower operating temperatures after BI precondition.



Reliability Plot for High Precision Reverence Voltage - VRLDSI B

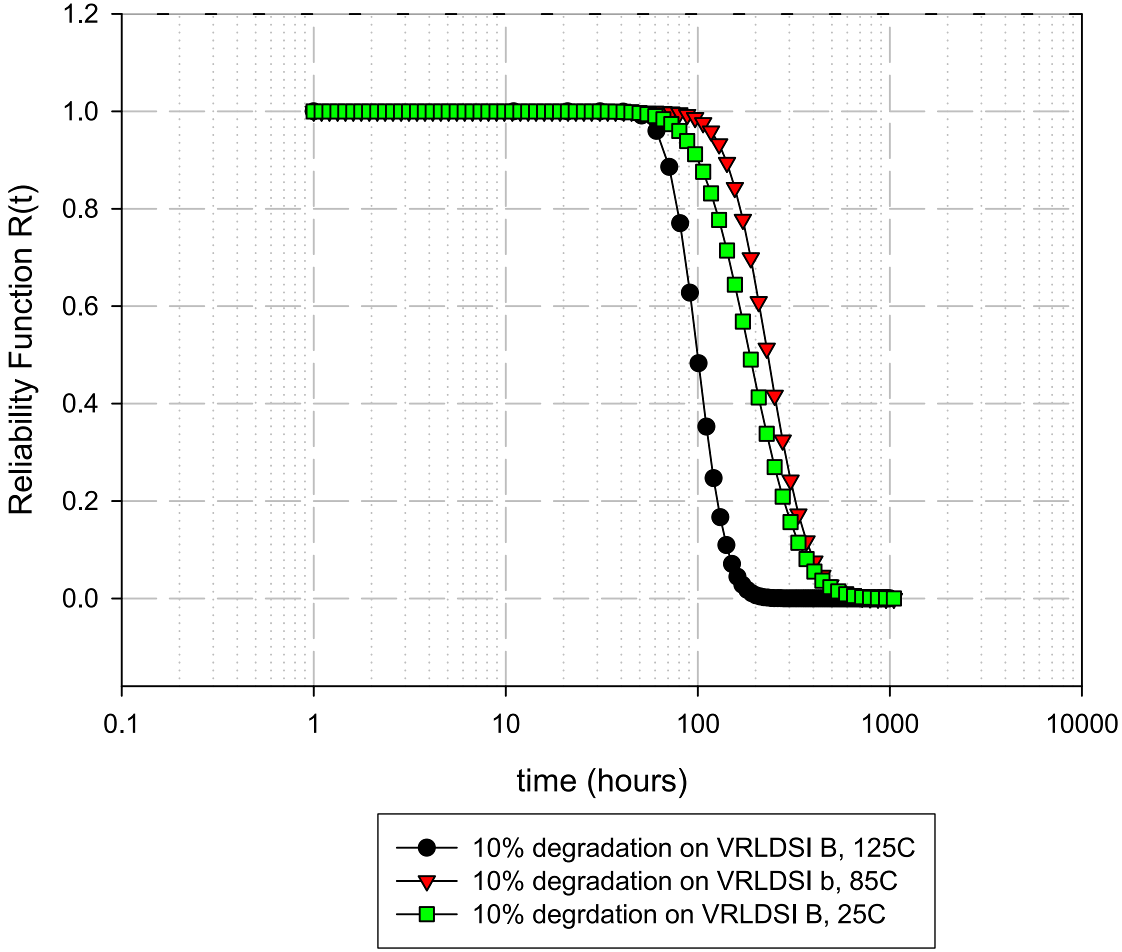
Post BI High Temperature Reliability Performance vs Degradation

- COTS PEM
- ss = 250
- Single vendor
- BI precondition (time/temperature)

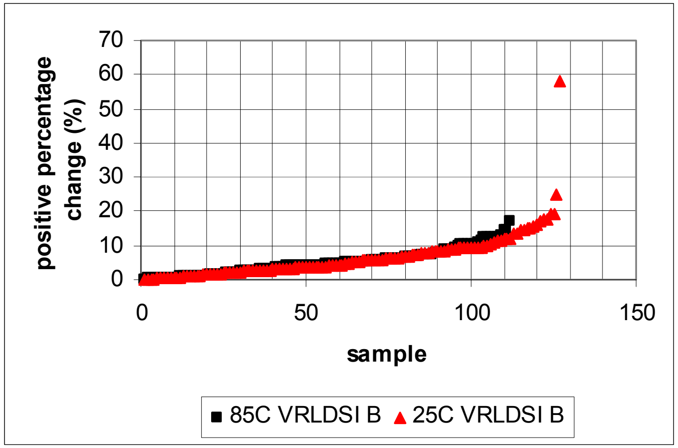


This plot demonstrates what reliability is expected with time depending on the % of performance degradation accepted by the user, for the intended application(s).

Reliability Plot for VRLDSI B at 125C, 85C and 25C



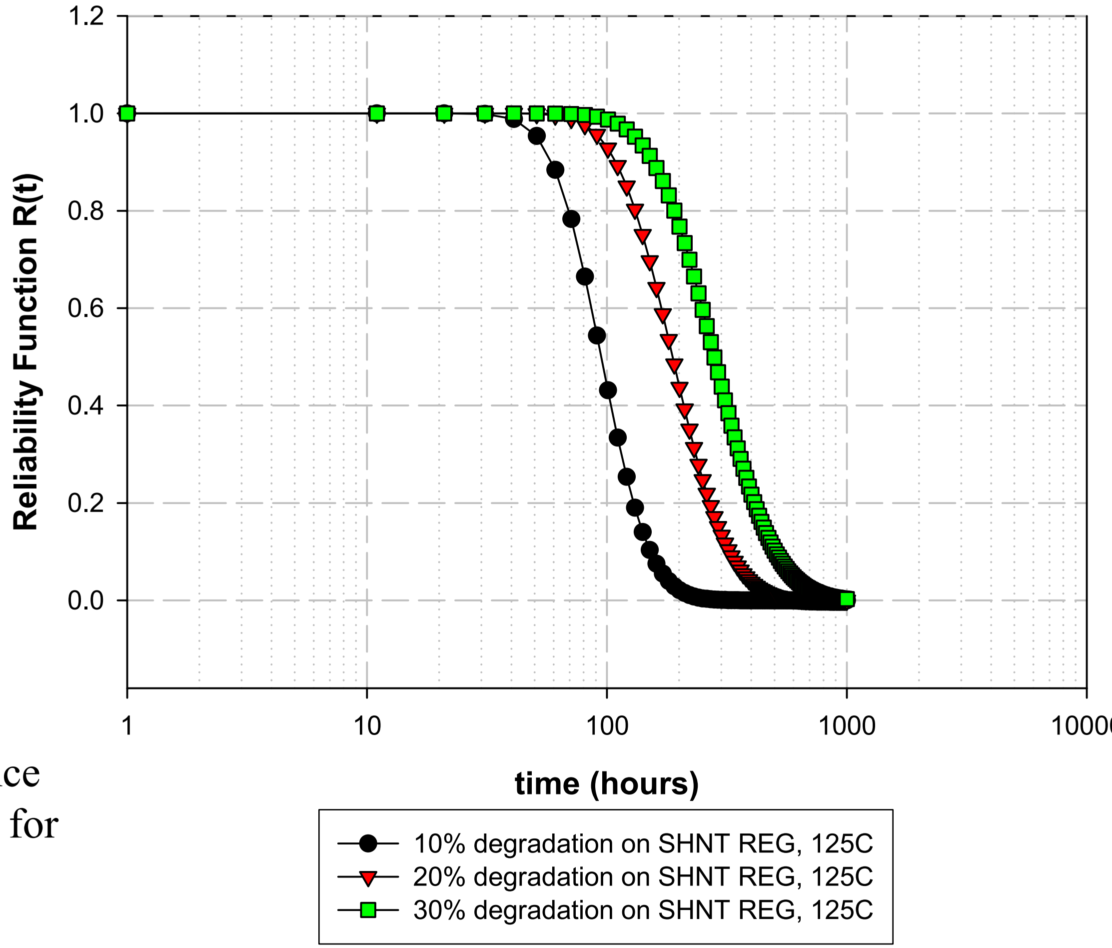
Why is R(t) similar at 85C and 25C ??



Reliability Plot for High Precision Reference Voltage - SHNT REG

Post BI High Temperature Reliability Performance vs Degradation

- COTS PEM
- ss = 250
- Single vendor
- BI precondition (time/temperature)

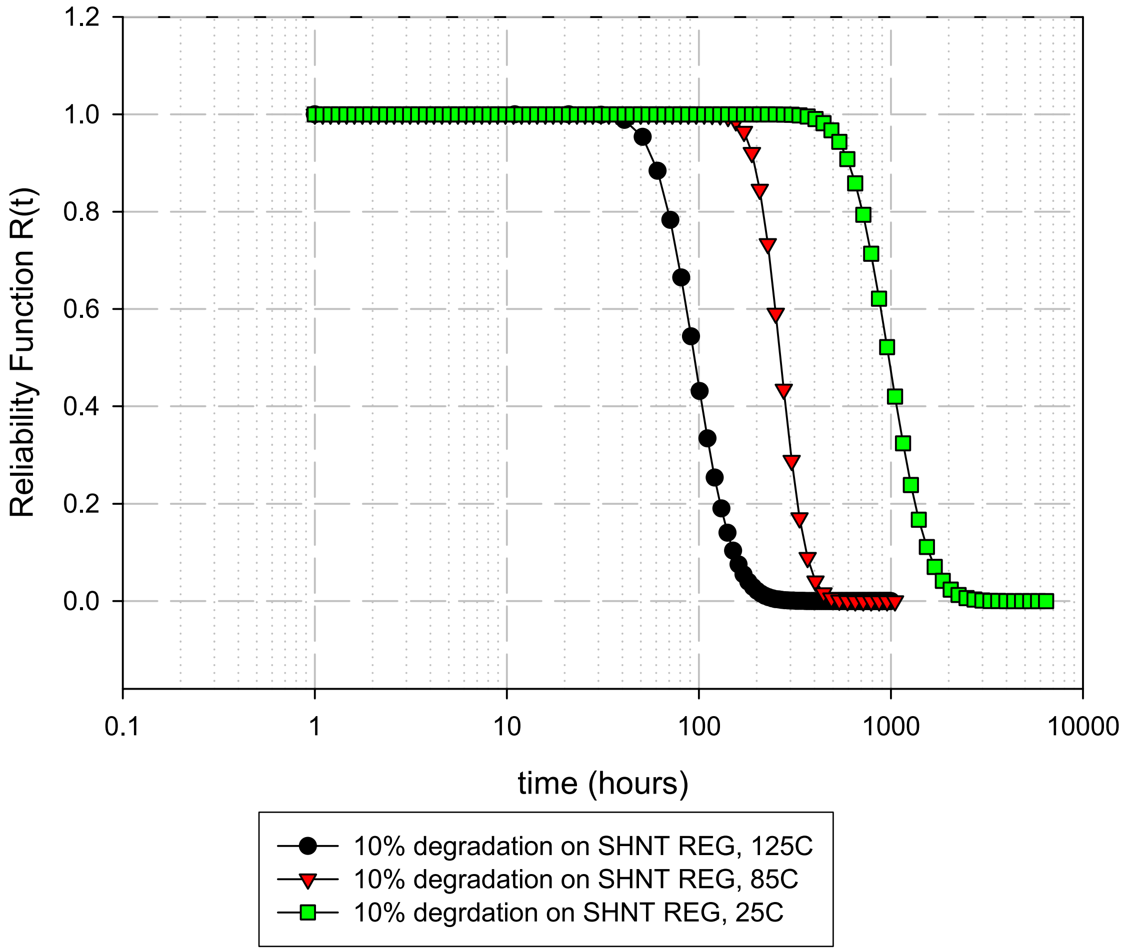


This plot demonstrates what reliability is expected with time depending on the % of performance degradation accepted by the user, for the intended application(s).

Reliability Plot for SHNT REG at 125C, 85C and 25C

Post BI Temperature Reliability Performance vs 10% Degradation

- COTS PEM
- ss = 250
- Single vendor
- BI precondition (time/temperature)

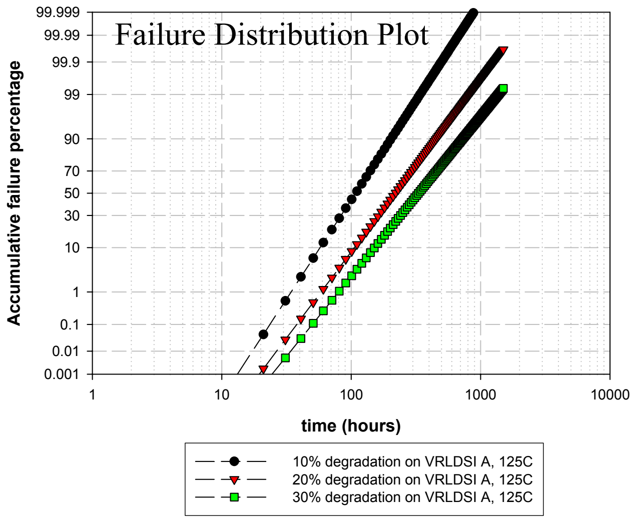


This plot demonstrates that better performance reliability can be expected at lower operating temperatures after BI precondition.

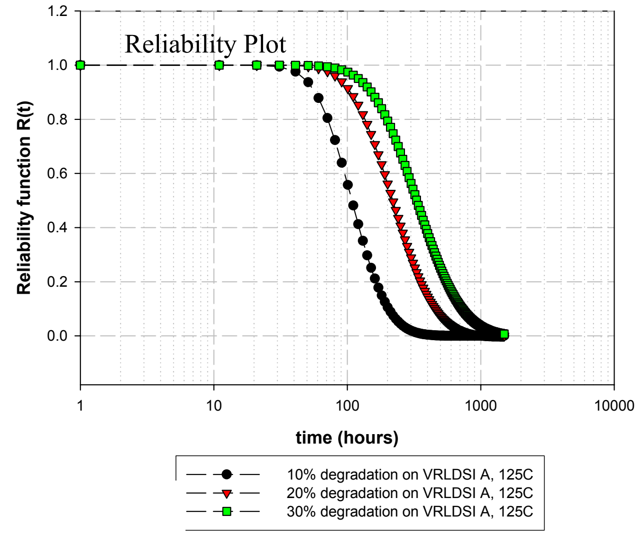
Reliability Plotting

1. Assumption:
   Linear function for
   log%drift versus log(t)

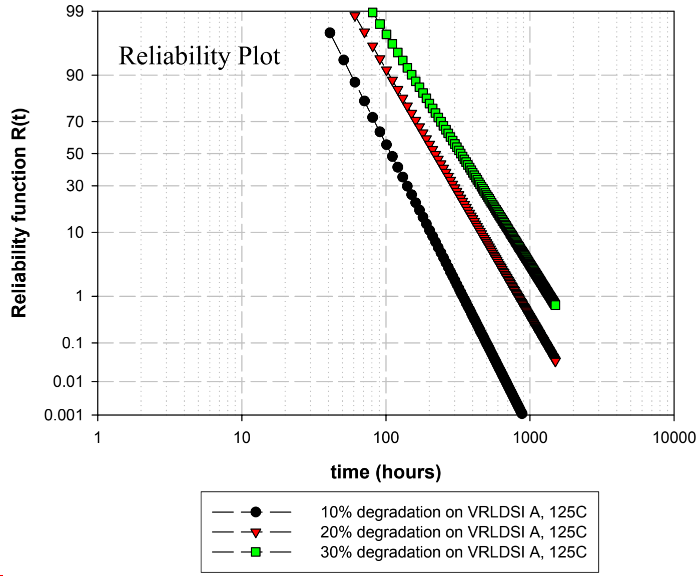
From BI data
VRLDSI A



2. Failure distribution plot
   To
   Reliability Plot

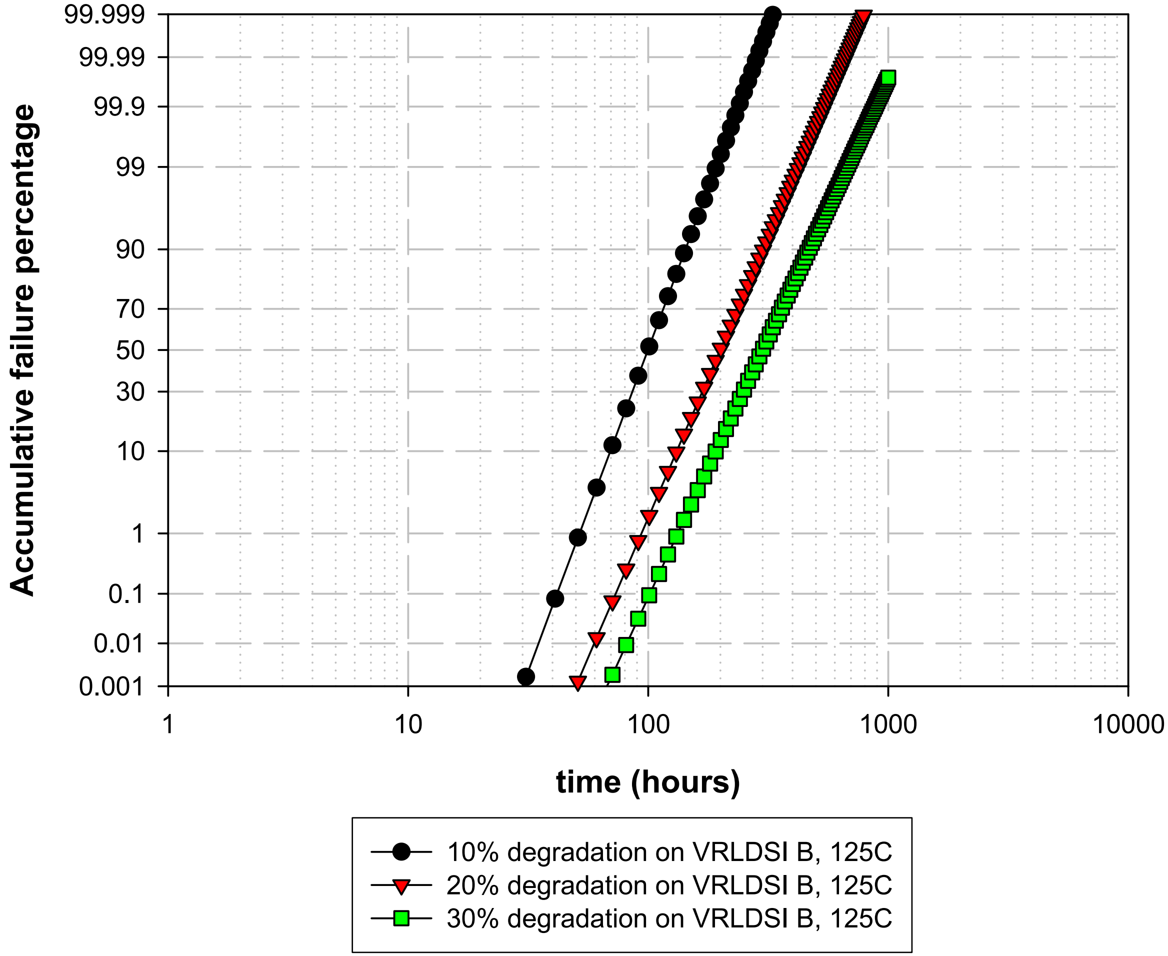


Same information

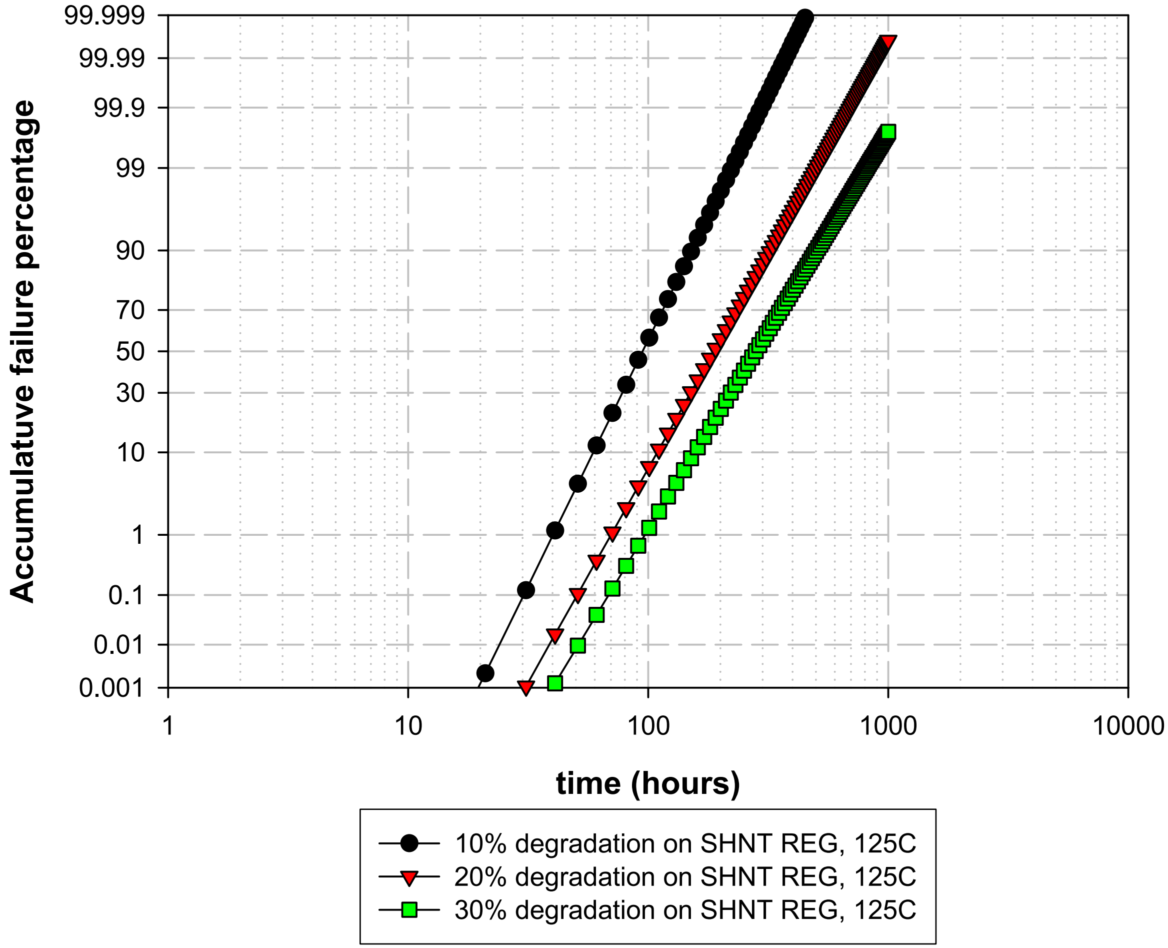


3.
Using Probability scale

Failure Distribution for VRLDSI B



Failure Distribution for SHNT REG



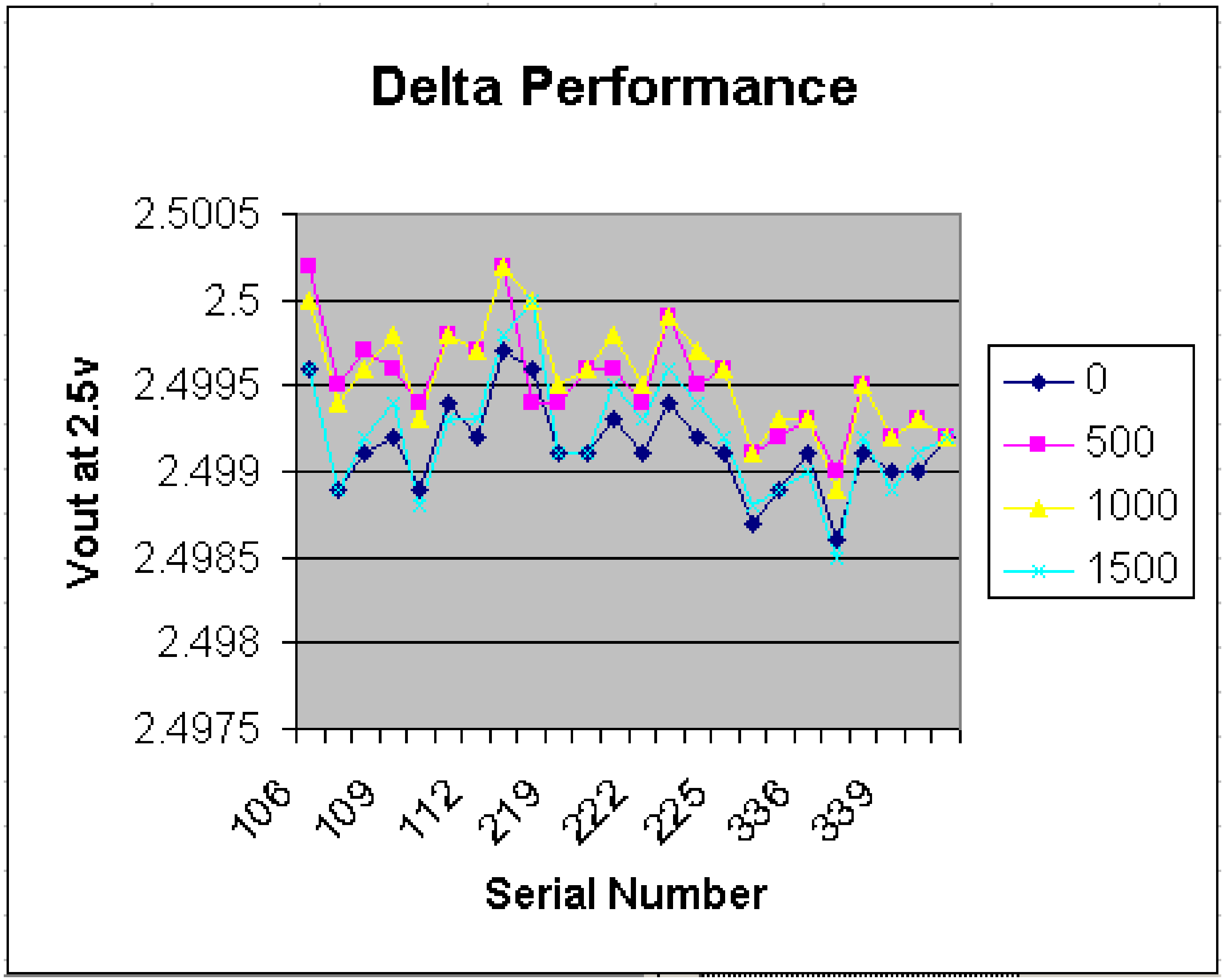
Vendor A FIT Burn-In Data
Reliability Analysis

"High Precision Voltage Reference"

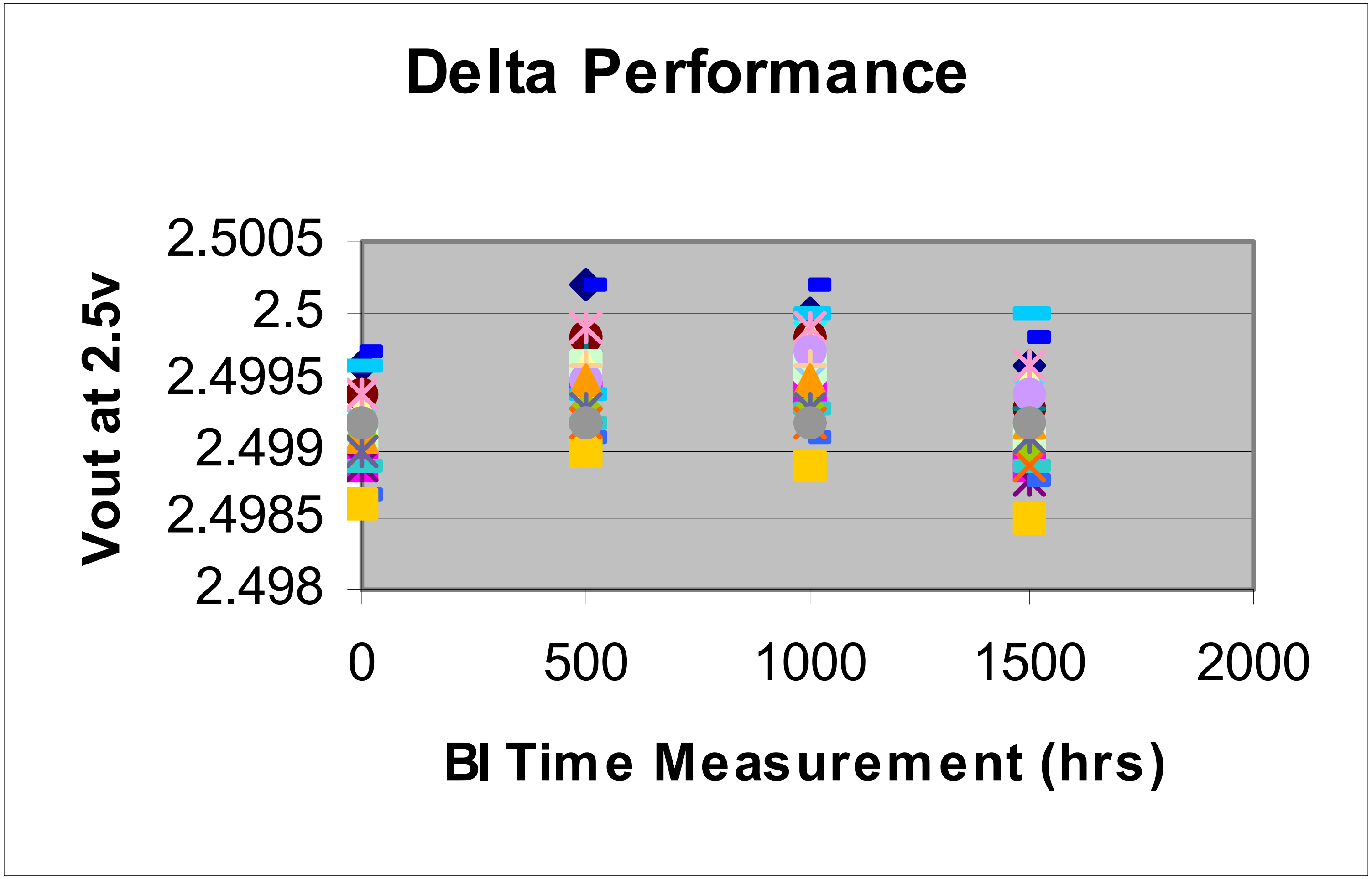
Preliminary Data Released for NASA Distribution Only

The purpose of this test is to determine the failure rate as a point estimate on a portion (sample) of the population using established confidence intervals.

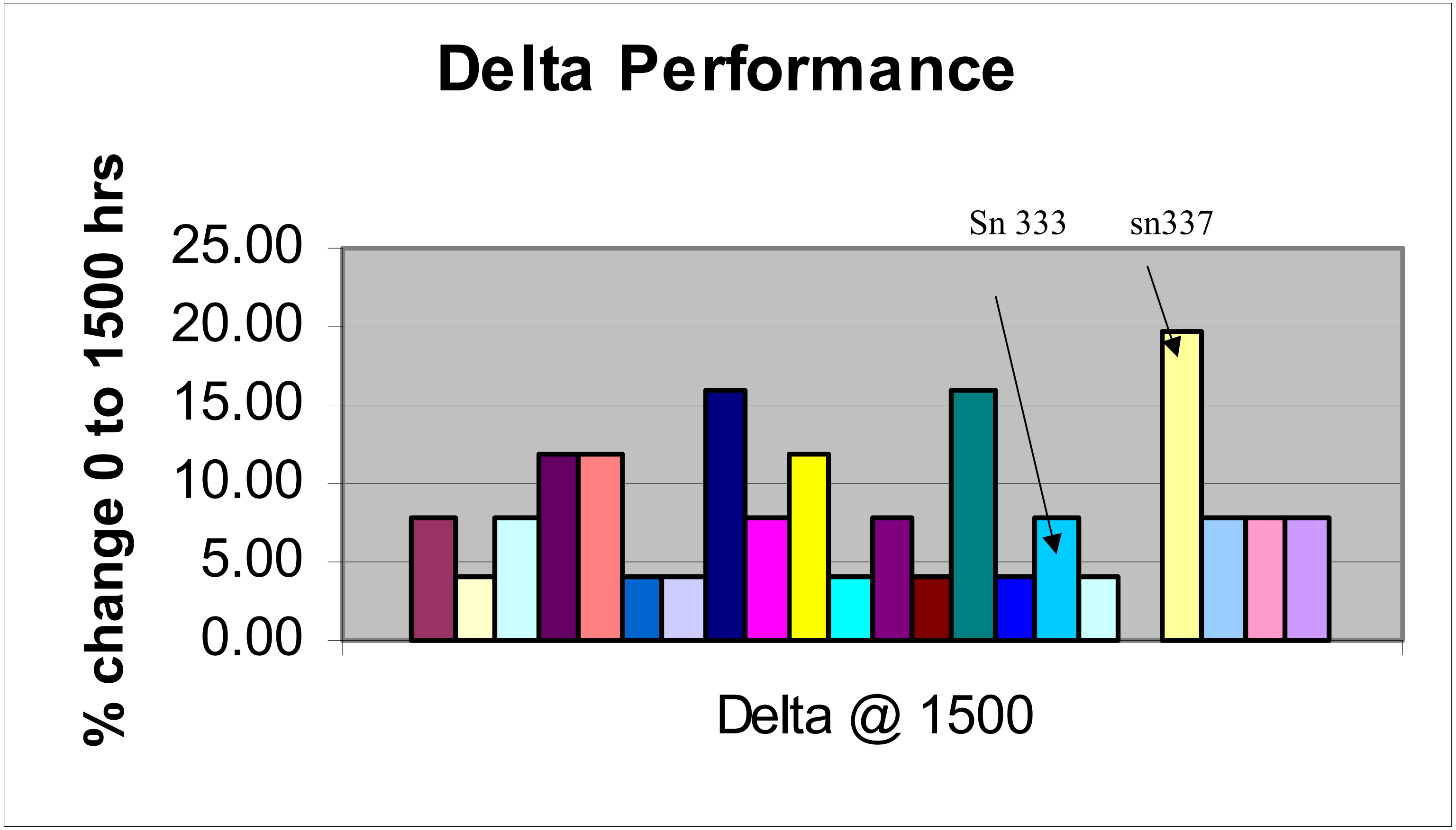
FIT 115C Static Burn-In Data, ss = 22, Vout at 2.5v, 25C



FIT 115C Static Burn-In Data, ss = 22, Vout at 2.5v, 25C



FIT 115C Static Burn-In Data, ss = 22, Vout at 2.5v, 25C



FIT 1500 hr 115C Static Burn-In Data, ss = 22, Vout at 2.5v & 3.0v, 25C

.	VOUT 2.5	VOUT 3.0
MIN	2.49874	2.99869
MAX	2.50126	3.00131

Accuracy : +/-0.0015%

Reject Summary

	VOUT 2.5	VOUT 3.0
500 hr point	sn333,337	sn333,337,335,340
1000 hr point	sn333,337	sn333,337
1500 hr point	sn337	sn333,337

There are 2 rejects from date code 0127 and no rejects from date codes 0112 and 0122 also sampled.

FIT 115C Static Burn-In Calculations

FIT CALCULATION:

Fr=Nf/Ndt
Nf=number of failures=2
Ndt=number of device hrs at test temperature of 125°C=33000
Ndt= Nd x Nh x At=864600
Nd=number of devices tested=22
Nh=number of hrs of testing = 1500
At=acceleration factor between Tj=125°C and 70°C=26.2
Using Chi squared table, Fr=χ2(x,v)/2Ndt where χ2=6.22(60%CL) and χ2=10.64(90%CL)
x=(1-CL) and v=(2N+2) degrees of freedom, where N is the number of rejects
At 60% Fr=3.589 x 10-6 and at 90 % Fr=6.153 x 10-6

NASA FIT Findings:

FIT = 3589 for 60%
FIT = 6153 for 90%

Sample Size: 22
Test time: 1500 hrs
Burn-in temperature: 115°C
Burn-in condition: Static
Rejects: test lab reported two rejects

Activation Energy (Ea) used is 0.7eV
Base plate ASSUMED is 70°C
Std outgoing lot FIT is UNKNOWN @ 90% CL

Vendor A Published FIT Data

Life-Test Data Summary by Process Technology								
Process Technology	Brief Technology Description	S-Size	Qty Fail	Total Device Hrs	FIT Rate 55°C 60% CL	MTTF 55°C 60% CL	FIT Rate 55°C 90% CL	MTTF 55°C 90% CL
BiCMOS	Bipolar + CMOS with minimum MOSFET feature size greater than 0.6um	26980	12	2763317240	5	192314946	7	146975239
Bipolar <2.5um²	Minimum emitter area <2.5um²	9699	1	1158723500	2	572969297	3	297894038
Bipolar >2.5um²	Minimum emitter area >2.5um²	12425	0	1038141660	1	1132983629	2	450858613
CMOS 0.18um	Minimum MOSFET gate length 0.18um	878	0	105997500	8	115681161	22	46034070
CMOS 0.25um	Minimum MOSFET gate length 0.25um	3906	2	453030500	7	145885765	12	85119010
CMOS 0.35um	Minimum MOSFET gate length 0.35um	5418	0	595412500	2	649807865	4	258584030
CMOS 0.5um	Minimum MOSFET gate length 0.5um	6754	3	663080860	6	158811747	10	99251998
CMOS 0.6um	Minimum MOSFET gate length 0.6um	16516	5	1468609880	4	233412066	6	158346320
CMOS 0.8 - 2.0um	Minimum MOSFET gate length 0.8 - 2.0um	3305	0	339104860	3	370084614	7	147271180
CMOS >2.0um	Minimum MOSFET gate length >2.0um	3729	1	316918840	6	156711040	12	81476067

Vendor A Initial Electrical Data (incoming inspection)
Reliability Analysis

"High Precision Voltage Reference"

Preliminary Data Released for NASA Distribution Only

The purpose of this test is to determine if the vendor's outgoing testing and or sampling plans guarantee the published data sheet specifications and performance over temperature.

Summary of Initial Electrical Rejects at 25C Testing (three date codes were 100% tested to data sheet at incoming)

Rejects: sn261 sn264 sn266 sn282 sn283 sn285 sn307 sn313 sn314 sn319 sn323 sn327 sn334 - total of 13/~250

These rejects failed data sheet spec for Vout either at 2.5v or 3.0v and were all from date code 0127. There were no rejects from date codes 0122 and 0112.

Note: Per vendor's website, the "Outgoing Quality Level" listed for electrical ppm = 0 for this specific part number and the majority for all other parts is 0 ppm or no greater than 1.4 ppm. Data posted for 3Q03

Vendor A Published Sampling Methodology

Samples are pulled from each lot based on either an LTPD or AQL plan. The overall PPM level is calculated using Method B of EIA Standard 554, which is summarized below. All reject types are included – functional, parametrics and downgrades.

Calculation Method Summarized

$$PPM = \frac{\Sigma\left(N_x * \left(\frac{d_x}{n_x}\right) LAR\right)}{\Sigma N_x} * 10^6$$

N_x = Total Quantity in Lot X

n_x = Sample Quantity in Lot X

d_x = Number of Rejects on the Sample n_x

LAR = Lot acceptance rate.

Vendor A Operating Life Test Data

Reliability Analysis

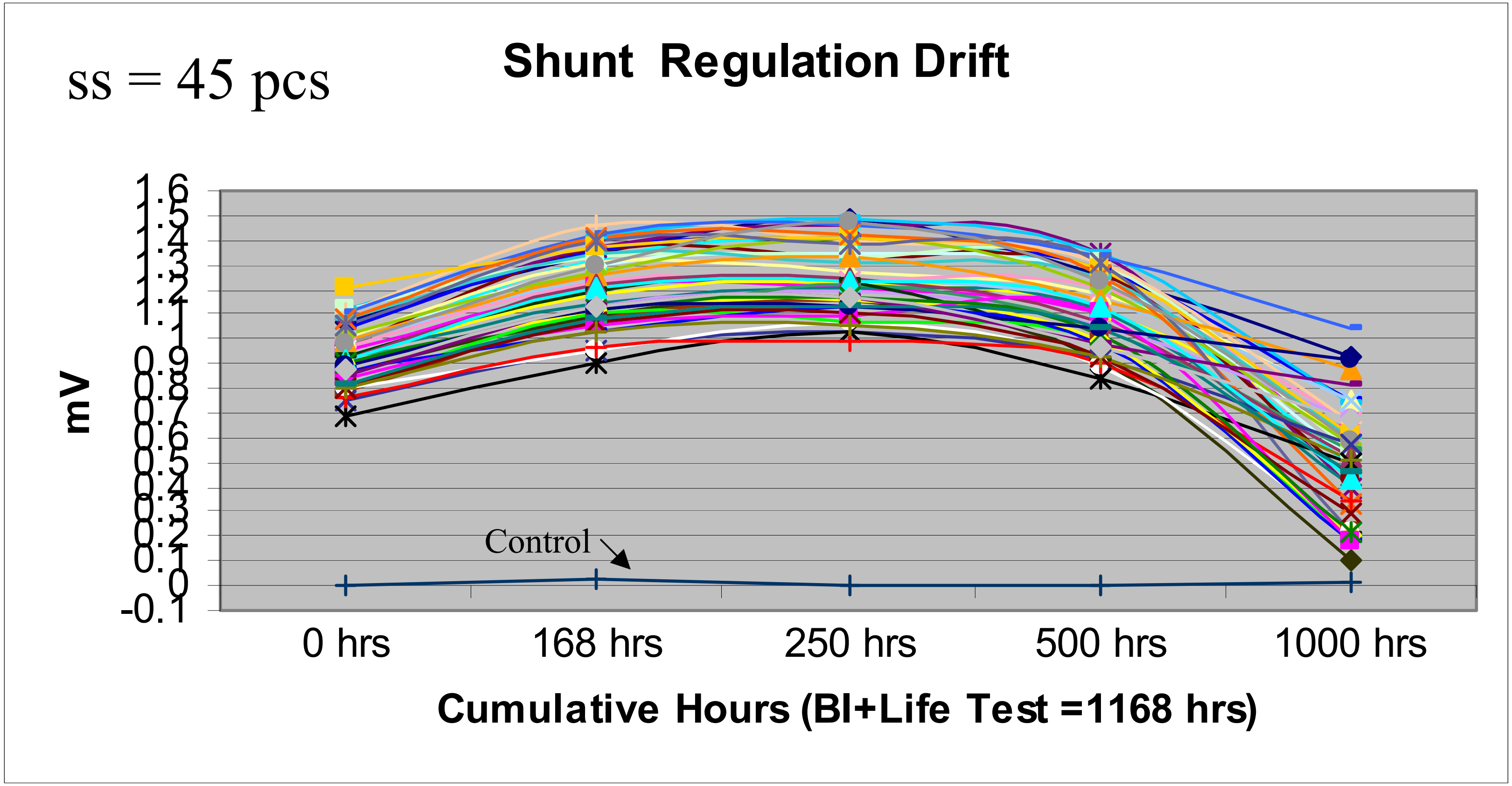
"High Precision Voltage Reference"

Preliminary Data Released for NASA Distribution Only

The purpose of this test is to evaluate the bulk stability of the die and to generate defects resulting from manufacturing aberrations that are manifested as time and stress-dependent failures.

Vendor A Operating Life Test Data

Specification is 1.5 mV max at +125C



Long Term Stability Specification = ± 20 ppm/1000 hr = ± .100 mV/1000 hr

Vendor A Incoming Inspection Data

Assembly/Process Quality Analysis

"High Precision Voltage Reference"

Preliminary Data Released for NASA Distribution Only

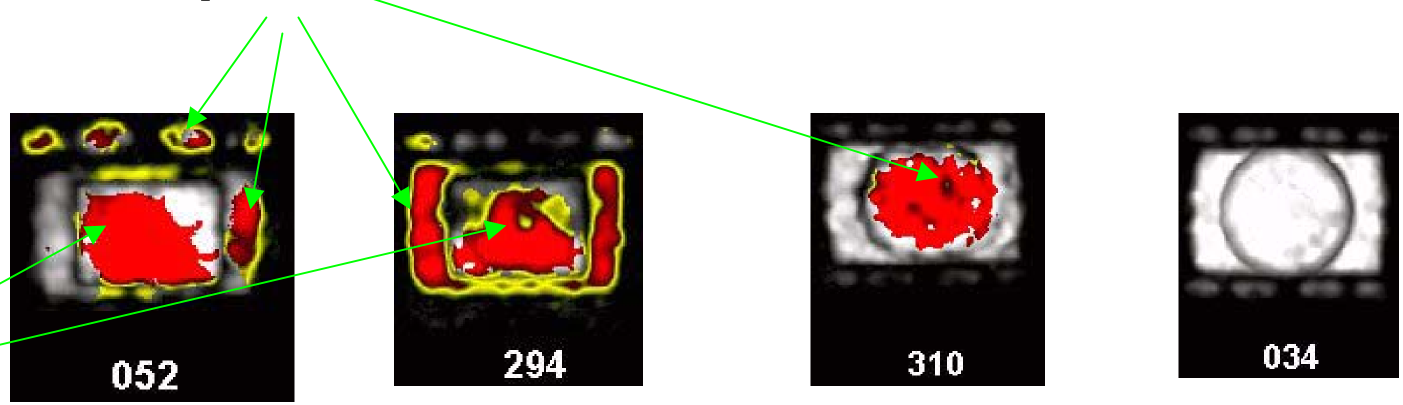
The purpose of this inspection is to evaluate the package assembly and wafer fabrication processes.

Vendor A CSAM Incoming Inspection Data

Assembly Quality Analysis

"High Precision Voltage Reference"

Delamination Examples:



Die Coat (nonuniformity)

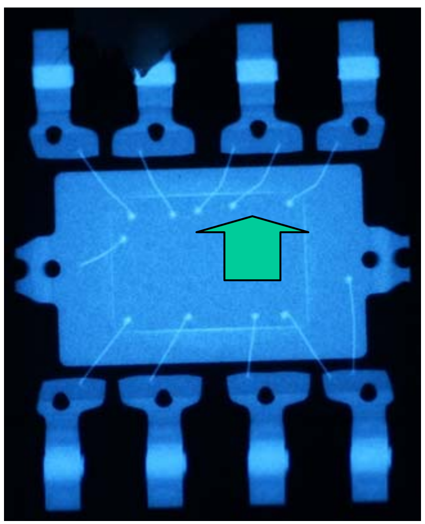
Topside Delam | Topside Delam | Backside Delam | Backside w/o Delam

	TOPSIDE									BACKSIDE						THRUSCAN		
	(top of lf)			(top of die)			(space around die)			(die paddle area)			(back of lf)			(die attach area)		
SN	LR	MR	HR	LR	MR	HR	LR	MR	HR	LR	MR	HR	LR	MR	HR	LR	MR	HR
Total	203	24	1	NA	NA	NA	34	120	74	224	2	2	153	0	0	NA	NA	NA

Vendor A X-Ray Incoming Inspection Data

Assembly Quality Analysis

"High Precision Voltage Reference"



Minor wire sweep found on 3 leads for one part

X-Ray Inspection (Wire Sweep)						
SN			LR	MR	HR	
031-105			70			
144151			8			
152*				1		
153-218			66			
256-334			79			
	Total		**223**	**1**	**0**	

Ref. Mil-Std-883, meth. 2012.6 for non-plastic, reject for slack wire within 0.002 in(0.05mm) of another wire.

Vendor A Outgassing Incoming Inspection Data
Assembly Quality Analysis

"High Precision Voltage Reference"

SAMPLE NO.	13	14	AVGE	16	17	AVGE	18	19	AVGE	20	21	AVGE
WT. LOSS %	0.42	0.42	0.42	0.29	0.26	0.28	0.41	0.36	0.39	0.32	0.44	0.38
WATER VAPOR RECOVERED, WVR, %	0.20	0.15	0.17	0.13	0.07	0.10	0.24	0.15	0.20	0.09	0.13	0.11
(WT. LOSS - WVR) %	0.22	0.27	0.25	0.16	0.19	0.18	0.17	0.21	0.19	0.23	0.31	0.27
VCM %	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.04	0.03	0.05	0.07	0.06
DEPOSIT	OPAQUE			LIGHT OPAQUE			LIGHT OPAQUE			OPAQUE		

NOTE: NASA ACCEPTANCE LEVELS ARE (WT. LOSS-WVR)%= 1.00% MAX
VCM% = 0.10% MAX.

All samples tested passed.

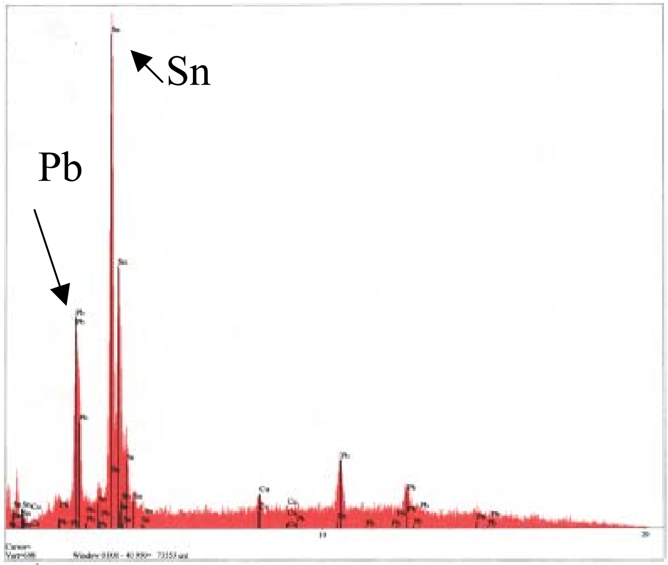
Vendor A Lead Coating Incoming Inspection Data

Assembly Quality Analysis

"High Precision Voltage Reference"

Lead Coating Examination

Date Code	External Lead Coating
0112	Lead-Tin Solder
0122	Lead-Tin Solder
0127	Lead-Tin Solder

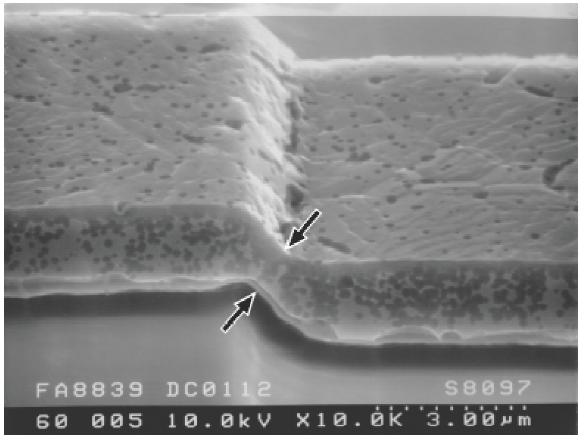


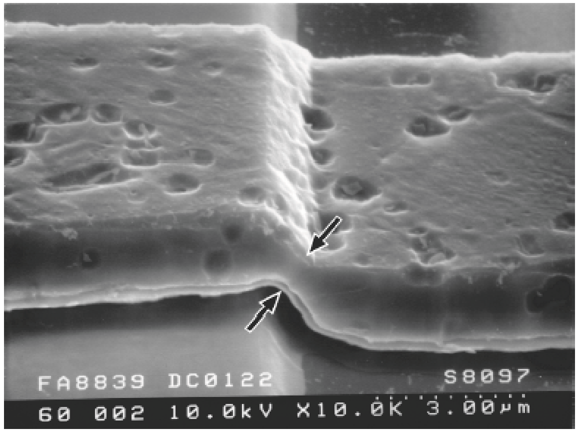
Comments: The composition of the coating on the external package leads was determined using x-ray energy dispersive spectroscopy (EDS).

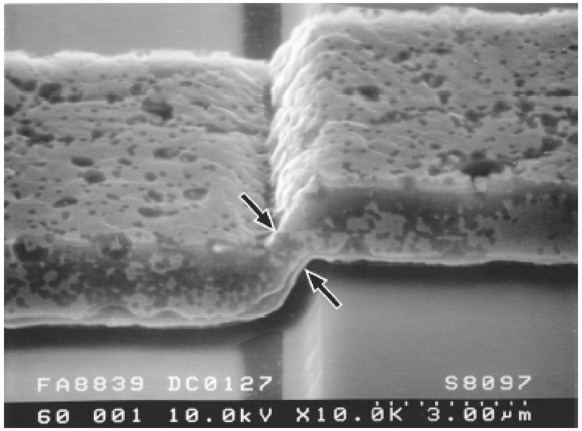
Vendor A SEM Incoming Inspection Data
Process Quality Analysis

"High Precision Voltage Reference"

Worst case step coverage seen on 3 date codes is 65%







Methodology Summary:

- A COTS PEMs high precision voltage reference part, built on a bipolar process, and encapsulated in an 8 ld SOIC package was tested and evaluated for its reliability and quality for use in NASA hardware.
- The part under this evaluation was one of five parts selected and chosen to be evaluated by NASA.
- A total of 250 parts per type were evaluated utilizing three different date codes to insure adequate sampling and meaningful statistics where possible.
- Testing was conducted by an outside approved test house while all analyses/engineer reviews were conducted by JPL/NASA parts engineers, parts managers, including test and reliability specialists.
- The analysis, findings, conclusions were solely based on the data and evidence collected and did not include any follow-up device failure analysis but did include initial destructive physical analysis.
- Careful attention was given to methods, procedures, and accuracy to insure the integrity and quality of the data taken

Burn-In Summary:

- A +125°C dynamic burn-in was completed on 250 parts to determine the infant mortality failure rate and identify any reliability issues that are intrinsic to the die and those that are extrinsically related to the package.
- There were no devices that failed catastrophically that is none were found to be non-functional.
- A number of critical parameters for this type of device drifted outside the manufacturer's maximum rated specification and or failed to stay within the manufacturer's drift specification.
- It was apparent that device performance degradation, as a result of the burn-in, correlated differently with the different data codes sampled.
- Using reliability prediction methods and assuming the drift was linear with time, some devices would experience up to 30% degradation within 1000 hrs of high temperature exposure (+125°C). Lowering the operating temperature would improve the reliability predictions.
- Some parameters also showed degradation when operated at +25°C after burn-in.

FIT Summary:

- A static burn-in was conducted on 22 samples with oven set at +115°C (the low temperature was calculated for the low glass temperature of the packaged and the high junction temperature of the device) for 1500 hours to simulate what the vendor does to report FIT numbers.

- Two serialized devices failed to meet the manufacturer's specification after FIT burn-in. All parts were tested before and after burn-in at +25°C including test monitoring at 500 hours and 1000 hours.

- Rejects only occurred from date code 0127 and none occurred from date codes 0112 and 0122.

- NASA FIT calculations, using an Ea of 0.7eV and a base temperature of +70°C, exceeded the manufacturer's posted FIT numbers for the device. FIT was 3589 @ 60% CL and 6153 @ 90% CL with 864600 device hours accumulated and a Tj of +125°C.

- Manufacture's published FIT is 2 @ 60% CL using a base temperature of +55C and a total of 1158723500 device hours.

Operating Life Summary:

- A dynamic operating life test was conducted on 45 samples, with oven set at +125°C for 1000 hours, to evaluate the stability of the die and or robustness of the design and package assembly.

- There were no occurrences of catastrophic failures or devices that failed device specification, although some parts were right on the edge of allowable limits with time progression.

- Although parts remained in specification during the entire life test, they did not meet the manufacturer's long term stability specification for the first 1000 hours (± 20 ppm/1000 hr).

- Device performance to specifications at +125C actually worsened within the first 418 hours (including burn-in time) and then gradually improved at the end of the 1168 hours of burn-in exposure. It appears that some annealing was occurring during the high temperature and long term exposure.

- The degradation seen during the first 168 hour burn-in was shown to continue to worsen during the first 250 hours of life test and then started to show improvement. This is an important correlation for any reliability predictions.

Incoming Electrical Summary:

- 100% incoming electrical test was performed to determine if the parts met the manufacturer's specifications across temperature.
- There were 13/250 serialized parts that failed the +25°C testing for either Vout = 2.5v or Vout = 3.0v.
- All rejects came from date code 0127. There were no rejects from date codes 0122 and 0112.
- Note that the manufacturer's latest outgoing ppm for this part was 0 ppm using a standardized calculation method.

Manufacturing Quality Summary:

- ❑ DPA was conducted on 22 samples to evaluate the package assembly and wafer fabrication processes.
- ❑ Scanning acoustic microscopy inspection of the package found significant topside delamination around the die periphery and some on the top of the leadframe within the package.
- ❑ X-ray inspection found very little evidence of wire sweep.
- ❑ Outgassing inspection found all samples to be within specifications.
- ❑ X-ray energy dispersive spectroscopy identified lead (Pb) as a component of the external lead coating along with tin (Sn).
- ❑ SEM inspection of metal step coverage found all samples to meet specification for all three date codes.

Conclusions:

- Quality of wafer fabrication was acceptable
- Package assembly was not acceptable mainly because of delamination
- Incoming electrical inspection was not acceptable indicating poor outgoing sampling by the manufacturer/ or not performing 100 testing.
- Burn-in reliability was not acceptable because of part parametric drift.
- FIT inspection was not acceptable because of two parts failing to meet specifications.
- Life Test reliability was not acceptable because of part parametric drift.
- Part will require full screening, qualification, and design performance evaluations prior to NASA's acceptance into any Space application.