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STATISTICAL INVESTIGATION OF SYMMETRICAL CMOS OTA DEGRADATION

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ABSTRACT

In this paper, symmetrical CMOS OTA degradation is investigated with using statistical methods. OTA' s are degraded using 4155 parameter analyzer and output current change is observed. An appopriate fitting curve is realised with MATLAB programme by taking into consedaration the error. Lifetime of the OTA's are determined with the %10 lifetime criteria. And probability density function is observed and lifetime is calculated statistically. Also, failure rate, reliability function and the cumulative distribution functions are observed.

Keywords: Symmetrical CMOS OTA*, Reliability Analysis, Statistical Methods.*

1. INTRODUCTION

Today's manufacturers are facing new pressures to develop highly sophisticated products to match rapid advances in technology, intense global competition and increasing customer expectations. As a result manufacturers must produce components in record time, while improving productivity, reliability, and overall quality of the component. It is a significant challenge to design, develop, test, and manufacture highly reliable products within short turn around times and rema in within the stringent conditions, imposed by both internal and external circumstances[1].

Estimating the time-to-failure distribution or long-term performance of components of high reliability products is particularly difficult. Most modern products are designed to operate

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without failure for several years. Thus few of such units will fail or degrade to a significant amount in a test of any practical length based on normal use conditions. For example, during the design and construction of a communication satellite, there may be only 6 months available to test the components which are meant to be in service for 15 to 20 years. The components used in submarine cables are often required to operate for 25 years under the sea. Very few test units are available that will actually reflect the life profiles of these components. For these reasons, Accelerated tests (ATs) are used widely in manufacturing industries, particularly to obtain timely information on the reliability of products[2-3]. To meet increasing competition, get products to market in the shortest possible time, and satisfy heightened customer expectations, products must be made more robust and fewer failures must be observed in a short development period. In this circumstance, assessing product reliability based on degradation data at high stress levels becomes necessary. This assessment is accomplished through accelerated degradation tests (ADT). These tests involve over stress testing in which instead of life product performance is measured as it degrades over time[4].

The failures of many manufactured products are caused by certain degradation mechanisms. For a particular unit of such a product, degradation measurements can be made over time. Such degradation measurements can be used to make inference on the lifetime distribution of the product. Degradation analysis for reliability has attracted considerable attention of statisticians, and engineers in recent years. Lu and Meeker [5] proposed a least-squares-based two-stage method for the inference on lifetime distributions using degradation data. Wu and Shao [6] considered direct ordinary, and weighted least squares procedures for degradation analysis. Meeker and Escobar [7] proposed a maximum likelihood procedure. Robinson and Crowder [8] explored a Bayesian approach. For other important references on degradation analysis, we mention, to name but a few, Boulanger and Escobar [7]; Tseng, Hamada, and Chiao [9]; Lu, Meeker, and Escobar [10].

Major advantage of performing reliability analysis based on performance (e.g., voltage, current, dielectric, etc.) degradation data is that it relates the reliability analysis to the physics of failure mechanism. Many papers have been written on reliability degradation modeling research and applications [1–8]. Basically, there are two types of reliability degradation modeling being widely used: the degradation path curve approach, and the graphical approach. The degradation path curve approach is based on the trajectory (so-called path curve) of performance degradation versus time [2–4]. This approach requires a known physics model of degradation. If a physics model is not available, a statistical method is needed to obtain the path curve. In general, the path curve is expressed as a function of time, containing both constant, and random coefficients. Numerical estimation of the parameters of a multivariate distribution function is required, and is usually computationally intensive. The graphical approach is widely used in practice [5–8]. It is based on statistical models.

The mean time expected to the first failure of a piece of equipment. It is a statistical value and is meant to be the mean over a long period of time. For constant failure rate systems, MTTF is the inverse of the failure rate or can be calculated using the $MTTF = \int_0^\infty t f(t)dt$ equation.

In this study transistor lifetimes are calculated using the degradation path curve approach. After that lifetimes are investigated statistically. Probability density function, reliability function and failure rate curves are obtained and MTTF calculated.

2. STATISTICAL METHOD

The object of primary interest is the reliability function, conventionally denoted R, which is defined as:

$$R(t) = \Pr(T > t) \qquad (1)$$

where t is some time, T is the time of death, and "Pr" stands for probability.Related quantities are defined in terms of the survival function. The lifetime distribution function, conventionally denoted *F*, is defined as the complement of the reliability function,

$$F(t) = \Pr(T \le t) = 1 - R(t) \qquad (2)$$

and the derivative of *F* (i.e., the density function of the lifetime distribution) is conventionally denoted *f*,

$$f(t) = \frac{\partial}{\partial t} F(t) \qquad (3)$$

f is sometimes called the event density; it is the rate of death or failure events per unit time. The failure rate(hazard function), conventionally denoted λ, is defined as the event rate at time *t* conditional on survival until time *t* or later,

$$\lambda(t)\partial t = \Pr(t < T < t + \partial t IT > t)$$
$$= \frac{f(t)\partial t}{R(t)} = -\frac{R'(t)\partial t}{R(t)} \qquad (4)$$

Change in output current is used for the degradation data. The behaviour of the change in output current fits the power curve and logarithmic curve in the literature[2].

3. RESULTS

Accelerated life test is applied to five same symmetrical CMOS OTAs seen in Figure 1. OTAs are produced by TUBITAK (Turkish Scientific and Technical Research Council) Laboratories with 3µ technology[12-13]. Power curve is presented as $Y = B.t^A$ and logarithmic curve is as $Y = A\ln(t) + B$. Degradation results are fitted both power and the logarithmic curves for 5 experiment results respectively in Figure 2 and Figure 3.

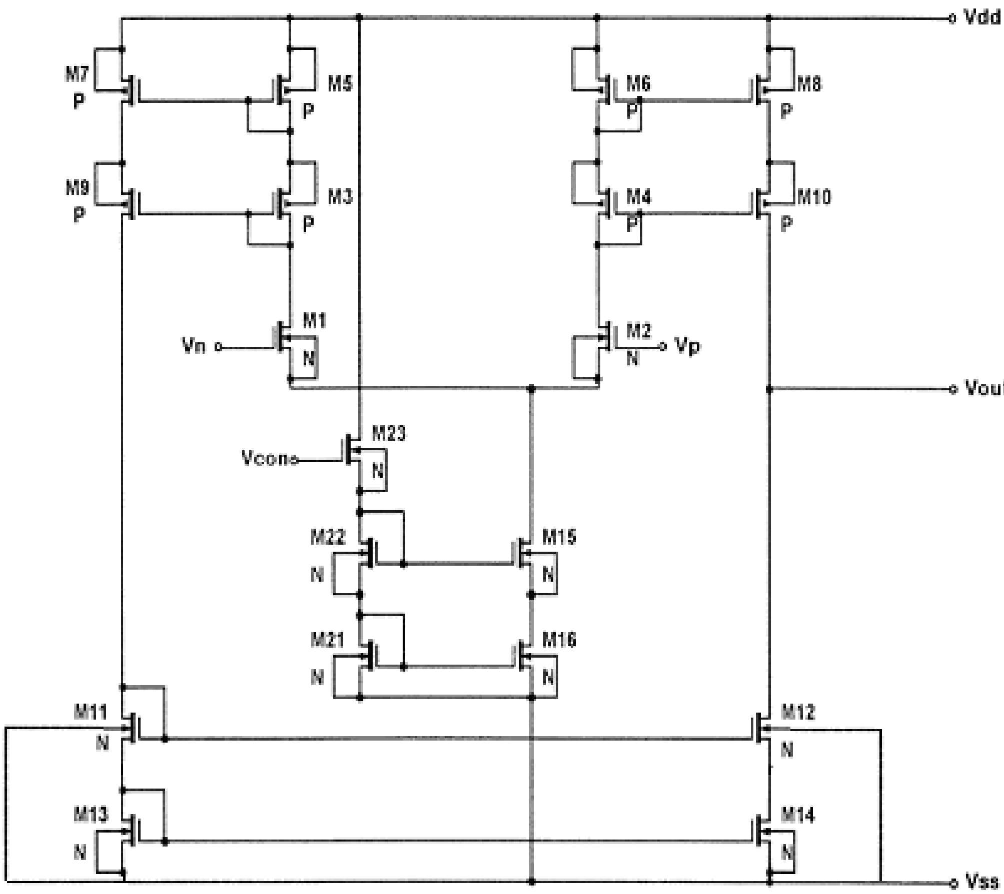

Figure.1: OTA realization used in experiments

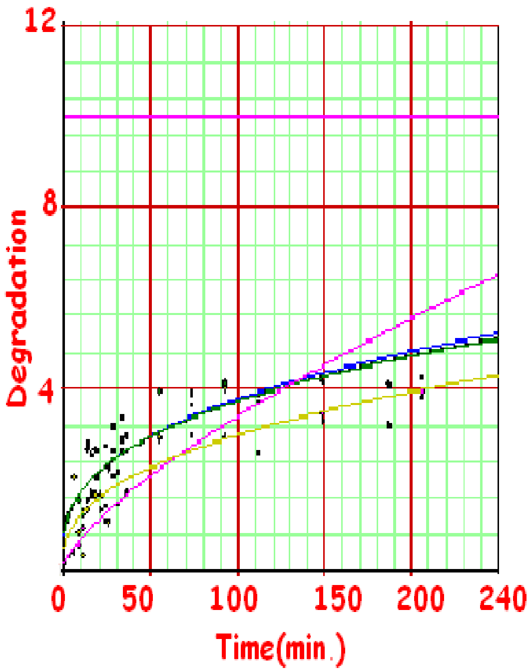

Figure.2: Power curve fitted to degradation data

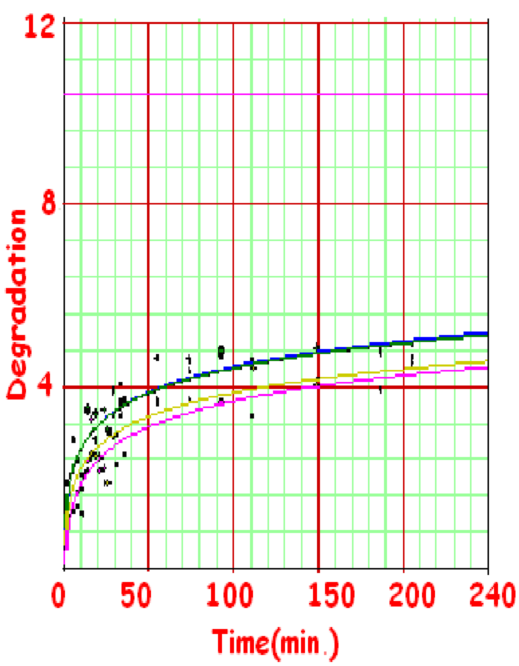

Figure.3: Logarithmic curve fitted to degradation data

In Table.1 A and B coefficients are seen for power and logarithmic cuve.

Table.1: A and B coefficients for curves

	B	A
	Power curve coefficients	
OTA1	0.8019663441	0.3539553012
OTA2	0.8137570676	0.3473666146
OTA3	0.8299310578	0.3428769927
OTA4	0.1489591538	0.7131710871
OTA5	0.5135829766	0.4017473705
	Logarithmic curve coefficients	
OTA1	-0.0117	0.8547874243
OTA2	0.0197	0.8377821571
OTA3	0.0454	0.8331976069
OTA4	-0.8245080446	0.8588552508
OTA5	-0.3249243575	0.7891767497

For each curve error mean and the variance is calculated using MATLAB. Results are seen in Table.2.

Table.2: Error mean and variances

	Variance	Mean
	Power Curve	
OTA1	0.2312	0.0322
OTA2	0.2250	0.0340
OTA3	0.2291	0.0359
OTA4	0.7774	-0.0504
OTA5	0.4461	0.1458
	Logarithmic Curve	
OTA1	0.1940	0.00002120
OTA2	0.1969	-0.00000724
OTA3	0.2029	0.00000084
OTA4	0.1910	0.00000075
OTA5	0.4649	0.00000203

It is seen that variances of the logarithmic cuves are smaller than the power curves. Thus, logarithmic curves are used for the change in the degradation data. Lifetimes of the OTA's are calculated by using the logarithmic curve equations and %10 lifetime criteria[11]. Results are seen in Table.3.

Table.3: CMOS OTA's lifetimes

	Lifetime(min.)
OTA1	122085.81
OTA2	149159.56
OTA3	154425.52
OTA4	297572.66
OTA5	480776.75

Probability density function of the OTA's lifetimes is extracted. Firstly it is assumed that the pdf of the lifetime is normal, lognormal, Weibull 2, weibull 3, gamma distributions. Loglikelihood values are calculated with Weibull++ 7 programme and respectively -66.26, -65.18, -65.56, -63.52, -65.69 values are handled. It is seen that distribution is Weibull-3 distribution and seen in Figure 4. For Weibull-3 distribution pdf, reliability and the failure rate equations are seen in Equation 5-7. These equations are can be extracted from Equation 1-4. The weibull parameters are seen in Table.4

The pdf equation is:

$$f(t)=\left(\frac{\beta}{\eta}\right)\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}\exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \quad (5)$$

Reliability equation:

$$R(t)=\exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \quad (6)$$

The failure rate equation:

$$\lambda(t)=\left(\frac{\beta}{\eta}\right)\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \quad (7)$$

Table.4: Weibull 3 parameters

Weibull Parameters	
shape parameter β	0,860500434
scale parameter η	117837,2812
location parameter γ	113318,9452

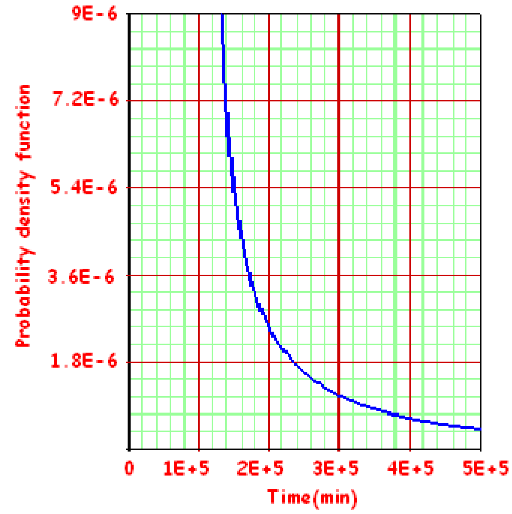

Figure.4: Probability density function of the OTA lifetime

The lifetime is calculated $2.4x10^5$ minute using the density function of the lifetime distribution.

Reliability function of the CMOS OTA is seen in Figure 5. The failure rate(or the hazard function) is seen in Figure 6.

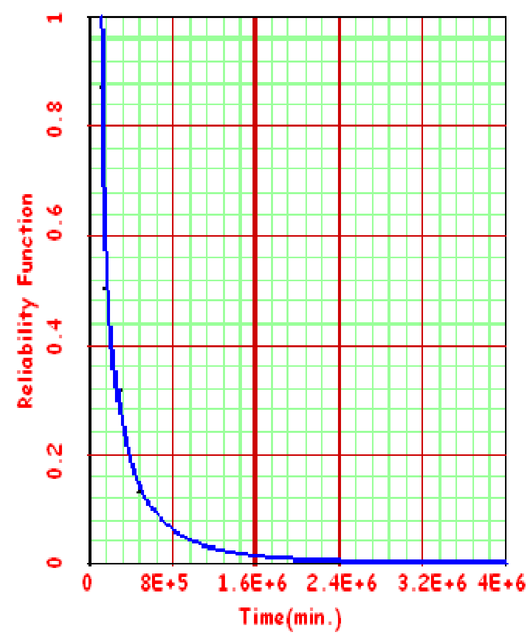

Figure.5: Reliability function of the CMOS OTA.

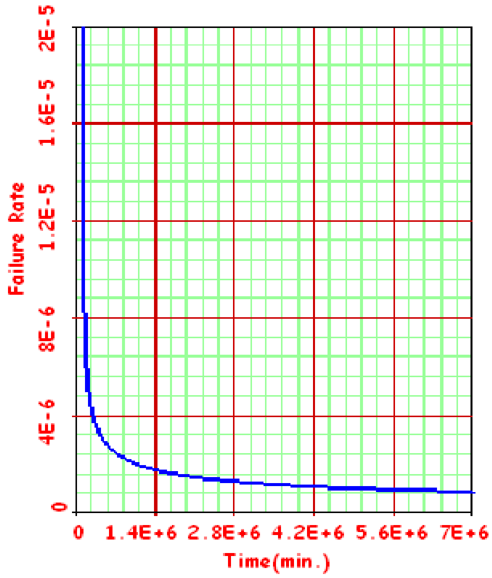

Figure.6: Failure rate curve of the CMOS OTA(β<1)

Using the failure rate curve failure rate of the CMOS OTA could be calculated for example $6x10^6$ minune operation(failure rate is constant around). From Figure 6 failure rate is $4.22x10^{-6}$ failures/min. It says 4.22 failures are estimated for every million minutes of operation. The mean time to failure(MTTF) is inverse of the failure rate and the MTTF is 1000000/4.22=236966.82 minute.

5.CONCLUSION

Symmetrical CMOS OTA degradation was investigated by using the degradation path curve and statistically in this study. Output current is realeased as degradation data and logarithmic curves exhabited to the changes in degradation data better than the power curves. Lifetimes are calculated and used for the statistical investigation. Probability density function, reliability function and the failure rate curves are presented. Failure rate and the MTTF is calculated. This work presents a degradation investigation method for any electronic devices.

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