CHEMICAL ENGINEERING TRANSACTIONS

VOL. 33, 2013

Guest Editors: Enrico Zio, Piero Baraldi

ISBN 978-88-95608-24-2; **ISSN** 1974-9791

A publication of

AIDIC

The Italian Association of Chemical Engineering

Online at: www.aidic.it/cet

DOI: 10.3303/CET1333187

Storage Lifetime Prognosis of an Intermediate Frequency (IF) Amplifier Based On Physics of Failure Method

Sheng Hong*, Zheng Zhou, Chuan Lv

School of Reliability and System Engineering, Beihang University, 37th Xueyuan Rd, Haidian District, Beijing, China
fengqiao1981@gmail.com

The Intermediate Frequency (IF) amplifier is one of the most important electronic components of a Radar guider, and its reliability estimation is a key issue in radar steady work. Limited by technology and time etc., it is very difficult to model, analyse, and estimate the reliability of an Intermediate Frequency (IF) amplifier by means of traditional methods, since Intermediate Frequency (IF) amplifiers are characterized by small sample size and long life, and it is hard to get large samples of the failure criteria in a short time. However, the failure criteria of the product are created by combining the Physics of Failure (PoF) analysis and the information from historic data about failed products. Based on the degradation trends and the failure criteria, the storage lifetime of the product can be predicted. Degradation of GaAs microwave device nearly related to stability of device's metallization which includes gate contact and ohmic contact. This article establishes a performance degradation model based on failure physics with uncertain activation energy. High temperature accelerant strass life test was performed on GaAs device to calculation the activation energy, and then uses the performance data and scanty life data to estimate the storage lifetime based on the new model. The instance analysis proves that the failure-physics-analysis-based method for the Intermediate Frequency (IF) amplifier is more effective in life forecast and consistent with engineering facts than the fake-life-based method.

1. Introduction

The application of the high-performance intermediate frequency logarithmic amplifier in radar, electronic countermeasures, communication field is great extensive (Huang and Pang, 1999). Technology that enables failure prediction of critical components (prognostics) has the potential to significantly reduce maintenance costs and increase availability and safety (Kacprzynski et al., 2004). By using storage life prediction of IF logarithmic amplifier, users could adopt appropriate measures before the occurrence of failure in order to avoid the irretrievable loss. Hence it is significant (Bowles, 1992). Physics-of-failure-based prognostics and health management (PoF-based PHM) is an approach that utilizes knowledge of a product's life cycle loading and failure mechanisms to design for and assess reliability (Fan et al., 2011).This is now becoming one of the critical contributors to efficient system level maintenance (Pecht and Gu, 2009). Li et al. (2008) of Beihang University have put forward the experiment method of Step Stress Accelerated Degradation Testing (SSADT) for the storage lifetime and evaluation of reliability of microwave electronic products. However, the model depends on the variance of sample greatly. Because the reliability experiment of the key component of radar seeker can only conducted on a very small sample, it is difficult to obtain the effective conclusion about the lifetime and storage reliability under the condition of technologies, funds and time (Denson, 1998).This paper builds the performance degradation model of intermediate frequency logarithmic amplifier from the perspective of the analysis of physical failure. Based on the model, the storage lifetime is predicted by using the performance data in accelerated aging test and the lifetime data. The evaluation of the storage lifetime of intermediate frequency logarithmic amplifier of a radar seeker is conducted finally.

Please cite this article as: Hong S., Zhou Z., Lv C., 2013, Storage lifetime prognosis of an intermediate frequency (if) amplifier based on physics of failure method, Chemical Engineering Transactions, 33, 1117-1122 DOI: 10.3303/CET1333187

2. Physical of failure model and lifetime analysis

2.1 Analysis of the main failure mode and failure mechanism

It can be seen that the failure of the intermediate frequency logarithmic amplifier is caused by the failure of GaAs bipolar transistor, according to the storage failure test results of the IF logarithmic amplifier storage for ten years. Hence, it can be concluded that the weakness of it is GaAs bipolar transistor. The main failure mode of GaAs bipolar transistor is the contact degradation of the gate schottky (Huang, 2002). The failure mechanism is the subside of gate metal and the spread of gate metal, which results in the decrease of the effective channel width and the drop of the channel doping concentration (it is resulted from the compensation effect of the deep level caused by the metallic contamination). The effect of the structure change on the electrical performance of the component reduces of zero grid voltage drain saturation current I_{DSS}, which causes the degradation of the intermediate frequency logarithmic amplifier power gain.

2.2 The analysis of the physical of failure model

Successful reliability prediction generally requires developing a reliability model of the system (Zio et al., 2012).The physical of failure model of zero grid voltage drain saturation current I_{DSS} caused the degradation of gate schottky according to formula (Yang et al., 2004) as follow,

$$\Delta I_{DSS}(\%) = -S_0 \exp(-\frac{E}{KT})\sqrt{t} \tag{1}$$

where S_0 is a constant, E is active energy, K is boltzmann constant, T is the storage temperature, and t is the duration when the temperature is T.

The high-performance intermediate frequency logarithmic amplifier cannot be repaired or examined, just like a black box. Test of the internal change of I_{DSS} is difficult. The model of zero grid voltage drain saturation current I_{DSS} caused by subside of gate metal built by undirected test is convenient to test.

The relation of the power gain and output U_0, I_0 can be obtained by the fundamental structure of intermediate frequency logarithmic amplifier. Then the relation of G and t can be obtained according to I_0 and t.

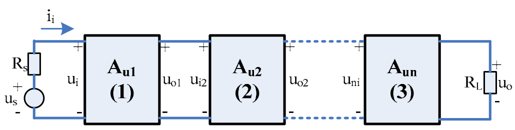

Figure 1 Equivalent diagram of N-order IF logarithmic amplifier

where,

$$A_u = \frac{u_o}{u_i} = \frac{u_{o1}}{u_i}\frac{u_{o2}}{u_{i2}}\frac{u_{o3}}{u_{i3}}\cdots\frac{u_{on}}{u_{in}} = A_{u1}.A_{u2}\cdots A_{un} \tag{2}$$

$$A_u(dB) = A_{u1}(dB) + A_{u2}(dB) + \ldots + A_{ui}(dB)\ldots + A_{un}(dB) \tag{3}$$

where A_u (dB) is the sum of each A_{ui} (dB). According to Kirchhoff theory of electric circuit, current of each level is i_i. Therefore, the power gain of the amplifier is linear weighted sum of all levels. Hence, we only need to analyse a certain level amplifier. Now we analyse an amplifier, and establish the relationship between the change of I_{DSS} and power gain. The equivalent schematic of circuit is shown in Figure 2.

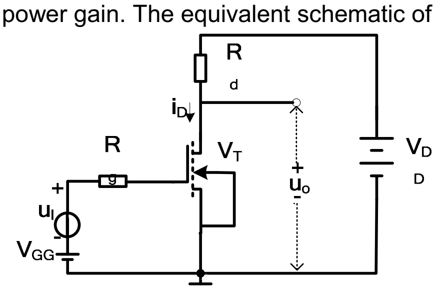

Figure 2 IF logarithmic amplifier equivalent schematic

According to the definition of the power gain:

$$G = 10\log P_L / P_{in} \tag{4}$$

Power is calculated as follows,

$$P_L = \frac{[(V_{dd} / R_d + R_x) \cdot R_x]^2}{R_L} = [(V_{dd} / R_d + R_x) \cdot R_x] \cdot i_D \tag{5}$$

Therefore, the output current is,

$$i_D = \frac{[(V_{dd} / R_d + R_x) \cdot R_x]}{R_L} = \frac{10^{\frac{G}{10}} \cdot P_{in}}{[(V_{dd} / R_d + R_x) \cdot R_x]} \tag{6}$$

where R_x is drain-source resistance, R_{ds} is load resistance and R_L is parallel resistance.

$$i_D = I_{DSS}(1 - \frac{u_{GS}}{U_{GS(off)}})^2 \tag{7}$$

Hence, $I_{DSS} = i_D / \mathrm{Z}$ $(\mathrm{Z} = (1 - \frac{u_{GS}}{U_{GS(off)}})^2)$ (8)

$$\Delta I_{DSS} = \frac{I_{DSS} - I_0}{I_0} \tag{9}$$

where I_0 is the initial output current before the test, and we use first test data in place of the initial one.
According to (4)-(9),

$$\frac{I_{DSS}}{I_0} - 1 = -S_0 \exp(-\frac{Ea}{KT})\sqrt{t} \tag{10}$$

$$\frac{I_{DSS}}{I_0} - 1 = \frac{i_{Dt} / \mathrm{Z}}{i_{D0} / \mathrm{Z}} - 1 = \frac{i_{Dt}}{i_{D0}} = 10^{\frac{G_t - G_0}{10}} - 1 \tag{11}$$

$$\ln - (10^{\frac{G_t - G_0}{10}} - 1) = \ln(S_0 \exp(-\frac{Ea}{KT})) + \frac{1}{2}\ln t \tag{12}$$

Boltzmann constant is K=1.38×10^{-23} J/K. So formula can be simplified into,

$$t = e^{2\times(A + \ln S_0 + \frac{E}{KT})} \tag{13}$$

where A is a constant which , related to the former power gain degradation value of IF logarithmic amplifier degradation.

2.3 Small sample method

Intermediate Frequency (IF) amplifier is one of the most important electronic components of a Radar guider. For such valuable product, the sample used for experiment and analysis is very small. Exponential distribution, as a less ideal distribution, is used for assessment. According to method (Han, 2004), the optimal lower confidence limit of reliable life can be calculated as follow steps.

According to (13), the lifetime T is exponentially distributed, and the average life expectancy of θ. For a given reliability R, the reliable life is,

$$t_R(\theta) = \theta In\frac{1}{R} \tag{14}$$

When the confidence level is 1-α, optimal lower confidence limit of $t_R(\theta)$ is,

$$t_{RL} = \frac{\ln R}{ln\alpha}\sum_{i=1}^{n} t_i \tag{15}$$

where t_1, t_2, t_3, …t_i is test time without any failure occurred.

3. Accelerated degradation test (ADT)

3.1 Implement of ADT

In order to supply the parameters (Activation Energy E_a, and coefficient S_0) in failure physical model, accelerated degradation test for IF logarithmic amplifier was carried to determine the unknown parameters. For long-term storage of environmental conditions, single level of constant temperature accelerated testing was applied to three types of device. According to the national military standard environmental test methods and the limits of the tested samples working temperature, the temperature of constant high temperature test is set at 100 °C.

The accelerated aging tests conducted a total of 500 h of 100°C constant temperature accelerated storage test. Every 50 h, the test sample was taken out and conducted at ambient temperature performance parameters detected when it cool down to room temperature. After test, sample was placed back into incubator and heated to 100 °C again. The experiments carried out in this procedure until the 500 h.

3.2 Experimental data analysis

After experiment, test data was collected and linear fitted. Intermediate frequency output power B(T2) at the test temperature T2 and be obtained, according to the intercept of the fitting line. Because the IF logarithmic amplifier sample have been stored for 10 y, the result from experiment is the 10-th year power output. From historical data, we can get 9th year data of power output. Using these two year data, we can get a second equation, and then .S_0 and E_a can be calculated according to the two equations.

A power-up test of IF logarithmic amplifier was carried on. From figure 3, power output of two accelerated test samples under at -60, -20,0 dB power input, slowly degraded with minor fluctuations as time goes by. Therefore, after reducing noise processing, the change rate of the output power at high temperature test can be obtained according to linear fitting of seven previous data.

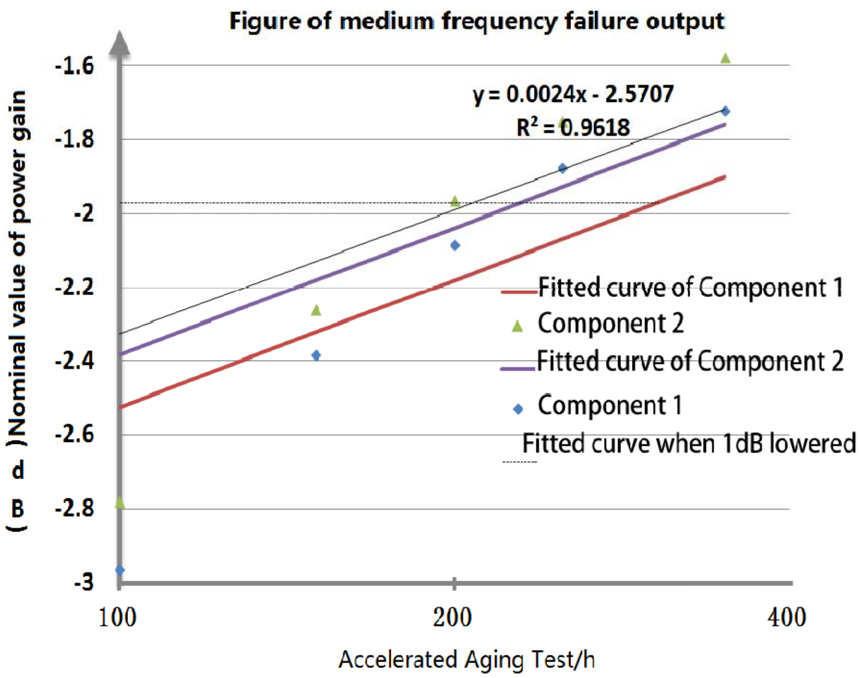

Figure 3 power output of IF logarithmic amplifier

From Figure 3, under 100°C, the output power is,

$$B(T_1) = \ln(S_0 \exp(-\frac{Ea}{KT_1})) = \frac{-(4.607+4.829)}{2} \tag{16}$$

$$\ln S_0 - 31.089Ea = -4.718 \tag{17}$$

According to 10th year experiment data and 9th year historical data, the second S_0 and E_a equation can be drawn as follows

$$\ln[-(10^{\frac{G_t-G_0}{10}} - 1)] = \ln S_0 - \frac{Ea}{KT} + \frac{1}{2}\ln t \tag{18}$$

$$-4.003 = \ln S_0 - 39.573Ea + 4.539 \tag{19}$$

From (17) (19), we can calculate, E_a=0.45eV, lnS_0=9.29.

4. The prediction of the storage of remaining life

According to the failure threshold, the output decreased 1db from the nominal value is considered to be failure. Take the nominal value using the ninth years testing data as the reference nominal data, set the fail point as G_t=-1.83 dbm and use the Initial measurements G_o=-1.18 dbm in the following formula:

$$A = \ln-(10^{\frac{G_t-G_0}{10}} - 1) \tag{20}$$

Get A=-1.97. According the formula (13) can get

$$t = e^{2\times(-1.97+\ln S_0+\frac{Ea}{KT})} \tag{21}$$

The t here is the life under T (Kelvin temperature),
The lose efficacy did not happened until the terminal time T in the test contained two product (n=2), Hence,

$$t_1 = t_2 = T \quad t_{RL} = \frac{\ln R}{\ln \alpha} 2T \tag{22}$$

This is a minimum sample. To this small sample size, it cannot look forward to getting a very high reliable life and a confidence lower limit of high confidence reliability life. If choosing the moderate reliability and confidence, R=70%, 1-α=2/3, then

$$t_{RL} = \frac{\ln 0.7}{\ln(1/3)} 2T = 0.6493\text{T} \approx \frac{T}{1.5}$$

To storage at room temperature (25°C), the life is about 280,000 h (getting from the formula (21)), and about 32 y, so the reliability year is t_{RL}=32/1.5=21.3 y. It conforms to the storage life 25 y that given by vendors.
According to analysis of microwave frequency logarithmic amplifier case, this method is more in lion with the actual engineering practice. It can effectively forecast the life of the electronic product through the life cycle.

5. Conclusion

It is very hard to do the life reliability assessment work due to the small sample characteristic of microwave frequency logarithmic amplifier. At the same time, valuable performance degradation data can be get from failure physics test, and these failure data based on product performance and failure can reflect the nature of the relationship. Analysis shows that the weak of frequency logarithmic amplifier is the GaAs dynatron. The primary failure mechanism as the gate metal sink, resulting in zero gate voltage of drain saturation current IDSS decreases will directly affect the recession if logarithmic amplifier power gain. So when the power gain reduce to the nominal value below a certain value of time, and then the time is the life expectancy logarithmic amplifier. This paper studies intermediate frequency logarithmic amplifier at room temperature (25 °C) and reliable storage life is 21.3 y, intermediate frequency amplifier and manufacturers to provide the storage life of 25 y basically. It is proved that life analysis method based on failure physics than assessment manual method of life is more reasonable, high accuracy. Compared with traditional method, physics of failure can efficient estimate various electronic components life. This method, focused on the main failure mechanism, can also help engineer improving the reliability of the device at the design stage.

References

Bowles, J. B., 1992, A survey of reliability-prediction procedures for microelectronic devices, IEEE Transactions on Reliability, 41, 2-12.

Denson W., 1998, The history of reliability prediction, IEEE Transactions on Reliability, 47, 321-328.

Fan J., Yung, K. & Pecht, M., 2011. Physics-of-failure-based prognostics and health management for high-power white light-emitting diode lighting. Device and Materials Reliability, IEEE Transactions on, 11, 407-416.

Han Y.G., 2004, Applied Mathematical Statistics, Beijing University of Aeronautics and Astronautics Press (in Chinese) ,China.

Huang K.J. and Pang Y.B., 1999, High-performance radar receiver logarithmic amplifier, Microelectronics, 29, 50-53.

Huang Y., 2002. The Basic Failure Modes and Mechanisms of GaAs Microwave Monolithic Integrated Circuit (MMIC), Electronic Product Reliability and Environmental Testing, 9-14.

Kacprzynski G., Sarlashkar A., Roemer M., Hess A. & Hardman B., 2004, Predicting remaining life by fusing the physics of failure modelling with diagnostics, JOm, 56(3), 29-35.

Li X. Y., Jiang T. M., Huang T. and Li G. Y., 2008, Storage life and reliability evaluation of microwave electronical product by SSADT, Journal of Beijing University of Aeronautics and Astronautics, 34, 1135-1138.

Pecht M. & Gu J., 2009, Physics-of-failure-based prognostics for electronic products, Transactions of the Institute of Measurement and Control, 31, 309-322.

Yang X., Ersland P. & Hoag D., 2004, Reliability of GaAs PIN switches for high frequency and high power applications, ROCS Workshop, 2004.[Reliability of Compound Semiconductors], IEEE, 135-149.

Zio E.,Golea L.and Pedronl N.,2012, Failure and Reliability Predictions by Infinite Impulse Response Locally Recurrent Neural Networks, Chemical Engineering Transactions,26,117-122 DOI:10.3303/CET1226020