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Reliability prediction system based on the failure rate model for electronic components

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Abstract

Although many methodologies for predicting the reliability of electronic components have been developed, their reliability might be subjective according to a particular set of circumstances, and therefore it is not easy to quantify their reliability. Among the reliability prediction methods are the statistical analysis based method, the similarity analysis method based on an external failure rate database, and the method based on the physics-of-failure model. In this study, we developed a system by which the reliability of electronic components can be predicted by creating a system for the statistical analysis method of predicting reliability most easily. The failure rate models that were applied are MIL-HDBK-217F N2, PRISM, and Telcordia (Bellcore), and these were compared with the general purpose system in order to validate the effectiveness of the developed system. Being able to predict the reliability of electronic components from the stage of design, the system that we have developed is expected to contribute to enhancing the reliability of electronic components.

Keywords: Reliability prediction; Failure rate model; Web-based; Electronic components

1. Introduction

The prediction of reliability is aimed at solving the problems identified prior to actual production or operation, thereby producing highly reliable products. To this end, although the result of the reliability prediction is important, it is also important to predict the reliability early on and offer feedback based on the results of the prediction. That is why reliability prediction is a significant way of enhancing the reliability required from the stage of design onwards, in order to meet the raised level of availability needed for the design review, trade-off for cost, or maintenance of a certain system or in the field.

Electronic components can be divided into parts, components, and units, or the assembly and system, and are easier to normalize for reliability prediction than mechanical components, so various prediction methods have been devised and are currently being used. These prediction specifications are mostly the modeled analysis results by collecting data from accelerating life tests and the fields.

Studies on the prediction of the reliability of electronic components started in the age of the vacuum tube and are still being conducted today, with numerous cutting-edge electronic components being produced. Palo (1983) developed a reliability prediction model for the SSI, MSI, and LSI devices. This model found the failure rate of electronic components for communication by adding the device scaling factor and field experience factor, which had not been considered in the previous models on the basis of the purely multiplicative calculation method. O'Connor (1985) studied the limitations of the MIL-HDBK-217D method with respect to the prediction of the

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failure rate of the digital microelectronic system. This study found that there was a limit to the reliability prediction because the distinction between the part level and the system level was blurred and the prediction specifications that were applied lacked information on the reliability of the newest electronic components. To solve this problem, a method of splitting the process into levels I and II was proposed, the former for prediction of the cost and logistics and the latter for prediction of the safety and reliability of the detailed system. Black (1989) conducted the reliability prediction of communication equipment by using the Telcordia (bellcore) prediction specification, and stressed the importance of the reliability of similar components and the reliability model. Valisena (1995) compared and analyzed the difference of reliability between the components meeting the specification and those that do not by using the MIL-HDBK-217 prediction specification. Jones (1999) proposed a method of predicting reliability by using the information on the failure rate of similar components and the system used in another environment. Foucher (2002) classified the different conditions of application of each model by dividing the reliability prediction method of electronic components into the statistical failure model, the method of using the failure rate database, and the life prediction using the physics-of-failure model. Cassanelli (2005) suggested an electronic components reliability prediction method that could be applied to the actual field. He suggested a reliability assessment method for new products by collecting empirical data and reliability information on similar components. The prediction model which is applied is a failure rate model based on the statistical method. Petch (2002) introduced the electronic components reliability prediction program based on the IEEE 1413 standard. In this standard, the reliability models for series, parallel, redundant and complex systems are addressed along with the FTA, repairable system, and Monte Carlo simulation. As in the previous studies on the reliability of electronic components, most of them only suggest methodologies of prediction, and only a few of them develop the prediction system. Therefore, in this study, we developed a Web system-based electronic components reliability prediction system for easy use by analyzing the prediction specifications based on the failure model, and thereby making a database from them. The prediction specifications included in the developed system are MIL-HDBK-217F N2, Telcordia (Bellcore), PRISM, and so on, which are often used for predicting the reliability of electronic components.

2. Method of reliability prediction

Reliability prediction methodologies can be divided into the following: a method of statistically building a failure rate model, a similarity analysis method based on an external failure database, and a life prediction method using the physics-of-failure model. The statistical method and the failure database method apply a statistical analysis method to the collected failure rate data, while the life prediction using the physics of failure model combines the models obtained through tests for predicting the reliability.

The method using the failure rate model was developed by statistically processing the failure data of each component collected in the laboratory and the field through reliability tests of electronic components. This method has a constant failure rate and finds the failure rate assuming that the exponent distribution is represented by the failure distribution. Among the main prediction models that are mostly used are MIL-HDBK-217F N2, Telcordia, HRD-5, NTT procedure, and PRISM. The input factors of these methods are the part type, count and quality level, application environment, and system configuration; these factors are quantified, weighted and then input in the failure rate calculation model equation. The output of the BS method is the average failure rate in general. The definition of the failure causes and the confidence level are not provided in most cases, but it is possible to calculate the success rate of the mission.

The method using the failure rate database is used for predicting the reliability of the newly designed components by making a database using the reliability of the previously made system or subsystem. In order to make such a failure rate database, all the causes of failure need to be defined, including the failure rate of the components, and that is why the failure cause analysis is the most important. The main failure databases are EPRD, HIRAP, REMM, and TRACS. The input factors of this method are the failure rate of similar components and the characteristic differences of the system. A top-down method, this produces the failure rate observed over time. Although the causes of failure are defined, the confidence level is not provided.

The physics-of-failure method requires the thermal, mechanical, electrical and chemical properties of the

Table 1. Method used for predicting the reliability of electronic components and the inputs and outputs.

Methods	Prediction standards	Inputs	Outputs
Statistical method	MIL-HDBK-217F N2, Telcordia, PRISM, HRD-5, NTT procedure, Siemens SN29500	Parts & Subpart types, quality level, environment, system configuration	Failure rates
Similarity analysis method using failure rate database	HIRAP similarity analysis method, REMM, TRACS	Failure rates for similar items, characteristics of production	Failure rates, which is monitored over time
Physics-of-failure method	Airbus-Giat, calceEP, calcePWA, CADMP	Material properties, Design characteristics, environment, loads	Average failure rate, life

materials constituting the electronic components to be applied to the failure model. For this, enough tests and analysis of the materials constituting the electronic components are needed, and a data management program is also required to utilize the data that have been built. The software for predicting the reliability of electronic components via the physics-of-failure method includes the Airbus-Giat method, calceEP, and calcePWA software. The input factors in this method need the properties of various materials of which the electronic components consist. The airbus-Giat method produces the average failure rate as the output and the calce software produces the life. Table 1 shows the method used for predicting the reliability of electronic components, the prediction standard, and the inputs and outputs.

These days some different methods are generally combined instead of using a single prediction specification for the accuracy of the reliability prediction, and the reliability prediction method is used in the design, development and manufacturing stages. New reliability prediction specifications such as the IEEE 1413 and SAEJ1000 have been recently introduced.

As shown in Table 1, the output values of the prediction specifications are failure rate and life, while input values require various factors according to the methods of prediction. Since the similarity analysis and physics of failure mythologies lack the failure rate database and the material property data of electronic parts required for reliability prediction, statistical methods are used widely in the fields. Open prediction specifications are in document form and commercial systems are expensive, raising difficulties in terms of their application. Therefore, a system of reliability prediction for electronics components which can be applied in the design and production phase is required.

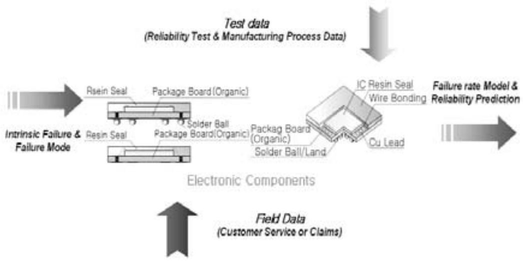

Fig. 1. Methods for predicting the reliability of electronic components based on failure rate model.

3. The reliability prediction specification based on the failure rate model

The reliability prediction specification of electric and electronic components is the RAC release TR-1100, which was announced by US RADC (Rome Air Development Center) in November, 1956; it provided the basis for creating the MIL-HDBK 217, which was created by the GIDEP (Government Industry data Exchange Program) of the US.

The reliability prediction using the failure rate model can calculate the failure rate within a relatively short period of time by means of the model equations drawn by a statistical method. Most of the failure rate models are built by modeling the failure data generated from the field and operation and the ALT (accelerating life test). The basic calculation method of the failure rate model is calculating the final failure rate of the electronic component by applying the environmental factors, stress factors and operational profile to the intrinsic failures of each component. One of the most noticeable features of this model is that it can find the failure rate by entering the laboratory data or the operational data of the field from the initial design stage where there is no reliability data. Fig. 1 shows the method using the failure rate model.

The most frequently used reliability prediction specifications based on the failure rate model are the MIL-HDBK-217F N2, which is specialized in military electronic components, Telcordia, which is specialized in communication components, and PRISM, which is specialized in military electronic components.

The MIL-HDBK-217 reference model was established by the US Department of State and Version F Notice 2 was announced in 1995 [9]. Although it does not include the reliability assessment method of the latest electronic technology, it is the most widely used specification from a worldwide perspective. The reliability prediction method is divided into the Parts Count method, which is used when it is difficult to find the precise value necessary for predicting the reliability at the initial design stage, and the Parts Stress method, which is applied at the system completion stage on the basis of the specifications and parameters according to the detailed design of the parts. In this study, the Parts Stress method was applied to predict the reliability of the electronic components.

In the MIL specifications, the basic factors affecting the reliability of electronic components are divided into environmental factors and quality factors. The factors of the environment in which the components are used greatly affect the failure rate along with the temperatures of the components. There are 14 environmental factors, which broadly divide into land, sea, and air, and they in turn divide into more detailed conditions. The values of the environmental factors defined in the MIL specification differ according to the components. The effect of the quality factors on the failure rate differs according to which method is used to manufacture the components and how strict a standard is applied to their production.

Eq. (1) is used to calculate the failure rate of the Microcircuit. λp represents the failure rate of each component, which is found by adding and multiplying each factor. C_1 and C_2 are the complexities which indicate the degree of integration of transistor or the logical gate. The value of C, which influences the failure rate, varies by the degree of integration of the package of electronic component. Temperature, the factor with the greatest influence on the reliability of the entire electronic component, is represented by π_T, which is calculated by the type of material (Silicon, GaAs) and manufacturing technologies used. π_A is the device application factor, π_E is the use environment factor, π_Q is the quality level factor, and π_L is the component maturity, which reflects the failure rate according to the time period during which the component has been used. These factors are found by using the MIL-M-38510 and MIL-STD-883 Screen/Test methods.

$$\lambda_P = (C_1\pi_T\pi_A + C_2\pi_E)\pi_Q\pi_L \tag{1}$$

The Telcordia (Bellcore) reliability prediction specification is usually used to predict the reliability of a serially arranged system, such as electronic components or assembly [10]. It is mostly used in communication components, but can also be applied to ordinary electronic components that closely meet the generic and product-specific requirements established by Telcordia.

The factor that affects the failure rate the most in the Telcordia prediction specification is the electric stress. This factor represents the percentage of the supplied voltage against the rated voltage (power). This specification assumes that the electronic components work at 40℃ with the weighted values of the GF (Ground Fixed) and GM (Ground Mobile) ranging between 1 and 15 as the environmental condition. The quality factors were divided by the manufacturer according to various standards for quality management and maintenance. The reliability prediction method of Telcordia is divided into three. Method I is used when there is no information necessary for reliability prediction in the initial design stage of the component at all. If there are any collected data in the manufacturing stage after the component is designed, more complex prediction methods are applied, namely Method II, which can use the test data and general data simultaneously, and Method III, which can use the tracking data of the field, the test data and the general data simultaneously. Eq. (2) is about the failure rate prediction of the assembly level of Telcordia, which is found by adding together the failure rates of all the components and multiplying that figure by the environmental factor.

$$\lambda_{PC} = \pi E \sum_{i=1}^{n} N_i \lambda_{SS\,i} \tag{2}$$

where λ_{PC} = the failure rate of the assembly
n = the number of the components constituting the assembly
N_i = the amount of components falling into the component type i
π_E = the environmental factor applied to the assembly
λ_{SSi} = the failure rate in the normal condition

A reliability prediction specification such as MIL-

HDBK-217 starts from the assumption that the failure rate of the system is decided by the failure rates of the components of which the system consists. This means that the important factors of a failure, namely the design fault, manufacturing fault, improper conditions or induced failure, are not reflected in the reliability prediction. PRISM provides the process grades of eight different causes of failure - parts, design, manufacturing, system management, wear out, no defect, induced, and software - along with the reliability prediction [11-13]. It is also able to predict the reliability of the electronic components and the system from the initial design stage to the stages of testing and operation. Eq. (3), which is the system failure rate calculation model used in PRISM, is characterized by the fact that it applies the process grade values used in the design and manufacturing of the system.

$$\lambda_P = \lambda_{IA}(\Pi_P \Pi_{IM} \Pi_E + \Pi_D \Pi_G + \Pi_M \Pi_{IM} \Pi_E \Pi_G + \Pi_S \Pi_G + \Pi_I \Pi_N + \Pi_W) + \lambda_{SW} \quad (3)$$

where λ_P = Failure rate of assembly or system
λ_{IA} =
Π_P = Parts process multiplier
Π_{IM} = Infant mortality factor
Π_E = Environmental factor
Π_D = Design process factor
Π_G = Reliability growth factor
Π_M = manufacturing process multiplier
Π_S = System management multiplier
Π_I = Induced process multiplier
Π_N = No-defect process multiplier
Π_W = Wear out process multiplier
λ_{SW} = Software failure rate prediction

4. Reliability prediction system

4.1 Prediction system

The Web is a system which can provide users with unlimited information without restrictions on distance and time. This system was developed as a Web-based information system capable of widely distributing the prediction specifications analyzed hereinbefore. The Web-based reliability prediction system developed in this study enables the user to predict the reliability of the electronic components or the system by using the Internet without installing another applied program [14].

Fig. 2 shows the failure rate model provision service using the Web. The three prediction specifications analyzed above have been turned into a database with the ASP (Active Server Page) and ODBC used for constructing the system.

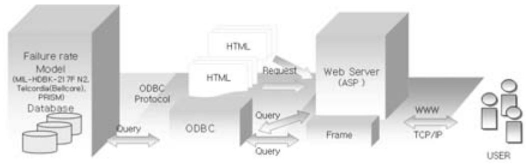

Fig. 2. Diagram of the Web-based system for predicting the reliability of electronic components.

Fig. 3. Selection of the reliability prediction item (on MIL-HDBK-217F N2).

The reliability of electronic components is predicted in the following processes. First, the user should select the desired failure rate model in the developed system. Second, the user should choose the electronic component whose reliability the user wants to predict. The classification of electronic components differs according to each failure rate model and is generally divided into categories and subcategories. Then, the stress data should be entered in precise values. If they are not entered, the default value is used. Lastly, the failure rate when the duty cycle is 100% is obtained.

Fig. 3. shows the screen in which the reliability prediction item is selected in the MIL-HDBK-217F N2. failure rate model. This specification divides into the categories of Micro Circuits, Diodes, Transistor, Thyristors and SCR, Optoelectronic, Detector, Isolator, and Emitter, with each category dividing into subcategories. The component selected in Fig. 3 shows the category of Micro Circuits and the subcategory of GaAs MMIC and Digital Device.

The MMIC digital device used as an example of reliability prediction is a key aspect of mobile communication, wireless multimedia, and high-speed optical communication. Its integrity is high enough to constitute a high frequency circuit with 3-5 MMICs according to the type of application. In addition, GaAs semiconductors are widely used to meet the need for compact, light-weight, and low power consuming electronic components.

The standard data of the GaAs MMIC for mobile communication devices manufactured by a compound semiconductor manufacturer was used as the input data for the reliability prediction. The applied complexity of the die was from 1 to 100, the temperature was 30℃, the application factor was a low-power device (100mW or less), the packaging type was hermetic, the number of pins was 10, the operational environment was ground-begin, the learning factor was 2 years or longer, and the quality factor was Class S. These standard data are subject to change in real use by the designer or manufacturer.

Fig. 4 shows the input of the reliability prediction data for the components selected above. The Die complexity of the GaAs MMIC components, usage temperature, applied factors, package failure rate, and the number of function pins is automatically weighted as the user chooses. The environmental factor, learning factor and quality factor are also automatically weighted as the user chooses.

The prediction data that have been entered calculate the failure rate of the electronic components according to the failure rate calculation model equation of the Micro Circuits proposed in MIL-HDBK-217F N2.

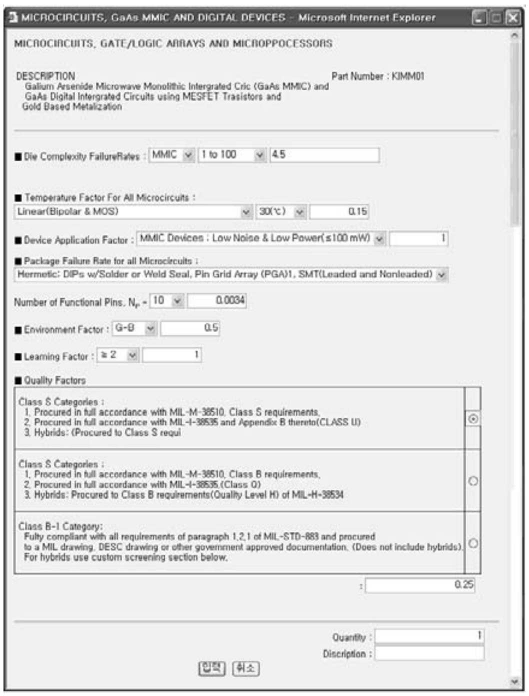

Fig. 4. Input of the prediction data for reliability prediction.

Fig. 5 is the result of the failure rate calculation of the GaAs MMIC component. In Fig. 5, the reliability is the failure rate of 0.169175 failures/million hours and the MTBF (Mean Time Between Failures) of 855,303. This is the reliability of the duty cycle 100% (24 hour operation each day) and is deemed to be good as a unit electronic component.

4.2 Comparison with the prediction specification and the commercial system

The results of the equation in the MIL-HDBK-217F N2 prediction specification and the commercial reliability assessment system were compared in order to evaluate the effectiveness of the developed system. As mentioned above, the failure rate equation, which is Eq. (4) of the Microcircuits in the MIL specification, is as follows.

$$\lambda_P = (C_1\pi_T\pi_A + C_2\pi_E)\pi_Q\pi_L \tag{4}$$

The values that are input equal the values input in Fig. 4 to calculate the failure rate, the results of which are as follows.

C_1 = 4.5 set to the range 1-100 parts
π_T = 0.15 set to 30℃
π_A = 1.0 set to Low Noise & Low Power
C_2 = 0.0034 set to 10 functional pins
π_E = 0.5 for ground begin
π_L = 1.0 for 2 or more years after production
π_Q = 0.5 for class S
Then
λ_P = (4.5*0.15*1.0 + 0.0034*0.5)*0.5*1.0
= 0.169175 failures/million hours

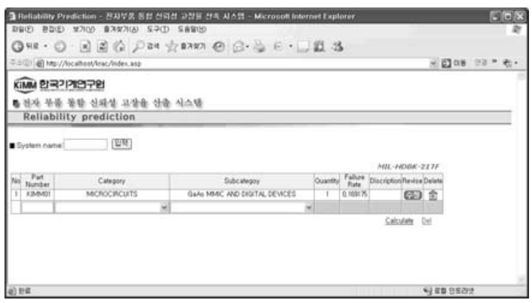

Fig. 5. Output of the result of the failure rate prediction.

Therefore, the failure rates calculated by using the MIL specification and the developed system are equal.

The result was also compared with that of the failure rate calculation of Relex, which is the commercial reliability assessment equipped with the MIL-HDBK-217F N2 standard with equal input values. Fig. 6 shows the result of the failure rate calculation of the GaAs MMIC component by using Relex [15].

As shown in Fig. 6, Relex selects MIL-HDBK-217F N2 as the failure rate model, sets the operating environment and temperature, and then enters the component and stress data for calculation. The calculated failure rate is 0.168538 failures/million hours, which is not equal but very close.

Table 2 presents the results regarding the reliability obtained with the developed system, the analytical approach by prediction specification, and the commercial reliability prediction system.

As the result of predicting the failure rate by using equal components and equal reliability prediction data, the result of the developed system is equal to that of the prediction specification and the general purpose system, so the prediction of the failure rate of the system developed for this study is deemed to be very accurate.

Table 2. Comparison of results for MIL-HDBK-217F N2.

Approaches	Failure rates (failures/million hour)	GaAs MMIC Digital Device
Developed (Web)	0.169175	Operating Temp. 30℃ Operating Environment GB Duty Cycle 100%
Analytical	0.169175	
Commercial (Relex)	0.168538	

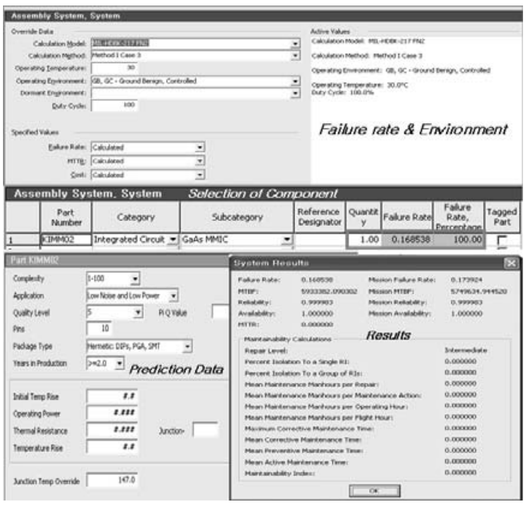

Fig. 6. The result of the failure rate calculation of the electronic component by using Relex.

5. Conclusion

In predicting reliability, not only the precision of the result but also the rapidity of assessing a component's reliability is important, because the process of enhancing the reliability of a component by providing quick feedback to the failure data generated during the operation of the components and the system from the design stage is necessary. In this regard, a Web-based system for calculating the failure rate on the basis of the failure rate model was developed in order to predict the reliability of electronic components. We analyzed MIL-HDBK-217F N2, Telcordia (Bellcore), and PRISM, which are the prediction specifications most frequently used for predicting the reliability of electronic components, turned the failure rate model equation and related factors into a database, and removed the inefficiency for the user to find the open prediction specification and input it into the equation of the component by maximizing the availability of the resources and the access of the user. In addition, the effectiveness of the system, which has been developed by comparing the result of the failure rate calculation using the prediction specification and that of the general purpose system, was validated. The developed system is expected to greatly contribute to enhancing the reliability of leading small and medium businesses producing electronic components, with multiple users being able to assess their reliability, while the general purpose system is difficult to operate because of the financial aspect. We are planning to construct a system capable of applying a prediction model that meets the characteristics of the target electronic components by adding a variety of prediction specifications to the constructed prediction specifications.

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