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Reliability prediction for automotive electronics

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Abstract
Reliability prediction for electronic products is a fundamental activity for automotive industry for several reasons: 1) understanding if a reliability goal is met, 2) comparing among alternative designs, or 3) evaluating reliability improvements. Reliability prediction is defined by the computation of the failure rates of all system/product electronic components. In the automotive field there are several guides designed for reliability prediction of electronic components, where the Siemens SN 29500 is well accepted by automotive industry. However, the Siemens SN 29500 standard, as well as other standards, gives the basis for failure rate calculation assuming constant environmental conditions, but not a step-by-step process when products are operating under different environments during their field life. Thus, in this article we present a step-by-step process to fully understand the implementation of the Siemens SN 29500 standard, when environment is not constant to obtain the failure rate/reliability value of a product, following an automotive electronic application.

Keywords: reliability prediction; failure rate; SN 29500; mission profile; failure in time.

Predicción de confiabilidad para electrónica automotriz

Resumen
La predicción de confiabilidad de productos electrónicos es una actividad fundamental en la industria automotriz por diferentes razones: 1) entender si se cumple con un objetivo de confiabilidad, 2) comparar entre diseños alternativos, o 3) evaluar mejoras de confiabilidad. La predicción de confiabilidad queda definida por el cálculo de la taza de falla de todos los componentes electrónicos que constituyen un sistema/producto. En el campo automotriz existen diferentes guías diseñadas para la predicción de confiabilidad de componentes electrónicos, donde el estándar Siemens SN 29500 es bien aceptado en la industria automotriz. Sin embargo, el estándar Siemens SN 29500, así como otros estándares, da las bases para el cálculo de la taza de falla asumiendo condiciones ambientales constantes, pero no muestra un proceso paso a paso cuando el producto opera en el campo bajo diferentes condiciones ambientales. De esta manera, en este artículo se presenta un proceso paso a paso, para el entendimiento de la implementación del estándar Siemens SN 29500, cuando las condiciones ambientales no son constantes, para obtener un valor de taza de falla/confiabilidad de un producto, siguiendo una aplicación electrónica automotriz.

Palabras clave: predicción de confiabilidad; taza de falla, SN 29500; perfil vida; fallas en tiempo.

1 Introduction

Automotive electronics industry demands high reliability in field applications, for this reason, it is required to predict the hardware failure rates on early development stages. This knowledge allows us to understand the ability of the product to operate in reliable form under given operation conditions [1], as well as to evaluate designs, compare design alternatives, support test planning, and track reliability improvements [2].

Automotive electronics products can have from hundreds to thousands of components, where the failure rate for each individual component represents its reliability of it and must be predicted. For this purpose, there are several standard-based methods, which categorize components and identify a set of parameters to predict their failure rates. In this sense, predictive models have been developed for electronic components, however, a disadvantage is that the models are not being updated according to the development of new

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technologies [2-5]. Even though, there are many options in automotive field. One of the most preferred standards is the Siemens SN 29500 [6]. Moreover, the standard ISO 26262, used for Functional Safety analysis, recommend its use in Part 5: Product development at hardware level [7].

Additionally, there are a set of software that cover the reliability prediction and include the most frequently used standards [2, 8], however, if there is not a well understanding of the standard, the use of the software or the standard by itself does not facilitate its application. Likewise, training and standards are expensive, and it is difficult to find manuals for application in literature. Then, due to the applicability of the SN 29500 standard for the reliability prediction, this paper provides a step-by-step process for failure rate calculation using this standard in a practical study case. This process could be used as a reference for practitioners in this field.

2 Siemens SN 29500 standard

As stated on SN 29500 standard, Siemens standard is mainly used by Siemens AG and Siemens companies as a uniform basis for reliability prediction [9]. Last update was done in November 2016, and it is composed for a total of 12 parts that are shown in Table 1.

Reliability prediction is calculated through failure rates, where failure rate is defined as the proportion of the failures that can be expected on average under given environment and functional operation conditions in a time interval [6]. The SN 29500 standard is recognized as representing a conservative approach to determining failures rates [10], and it specifies the failure rate values in FIT (failures in time), where one FIT corresponds to one failure in 10^9 component hours.

In first instance, the SN 29500 standard provides reference failure rates (λ_{ref}), which mean the corresponding component failure rate when it operates under the standard defined reference conditions (time interval, operating voltage, mean ambient temperature, environment, etc) i.e., when the product operates at 40°C degrees.

Since reference condition will not always be the same, the SN 29500 standard also provides conversion models to calculate failures rates depending on stress operating conditions as voltage, current, temperature, among others. For example, eq (1) represents a conversion model to calculate a failure rate under operating conditions:

$$\lambda = \lambda_{ref} \; x \; \pi_U \; x \; \pi_I \; x \; \pi_T \qquad (1)$$

where λ_{ref} is the failure rate under reference condition, π_U is the voltage dependence factor, π_I is the current dependence factor, and π_T is the temperature dependence factor.

There are several conversion models to be used, the chosen conversion model will depend on the type of component being evaluated as will be seen on section 3.2.

Next section shows the step-by-step process for reliability prediction based on SN 29500 standard through a study case.

Table 1.
SN 29500 standard parts

Part	Last update	Name
1	01-2004	Expected values, general
2	09-2010	Expected values for integrated circuits
3	06-2009	Expected values for discrete semiconductors
4	03-2004	Expected values for passive components
5	06-2004	Expected values for electrical connections, electrical connectors, and sockets
7	11-2005	Expected values for relays
9	11-2005	Expected values for switches and buttons
10	12-2005	Expected values for signal and pilot lamps
11	04-2015	Expected values for contactors
12	02-2008	Expected values for optical components
15	11-2016	Expected values for electromechanical protection devices in low voltage network
16	08-2010	Expected values for electromechanical control pushbuttons, signaling devices and position switches in low voltage networks.

Source: Siemens SN 29500 standard, 2016.

3 Automotive electronic study case

In this paper, a monitor used on a vision system is used as an engineering application example, reliability prediction is calculated by part stress analysis based on field life profile, temperature mission profile, and Siemens SN 29500 standard.

3.1 Inputs for the analysis

Key inputs for a reliability prediction based on a part stress method are Bill of Materials, temperature mission profile, life profile, schematics, and components data sheets.

Bill of Materials (BOM) is the main input, since it shows the components that build all the system. Therefore, it shows the components that must to be evaluated and their reliability to be determined. BOM must have clearly identified the type of component and enough information to track main characteristics of each component as the supplier's name and supplier part numbers.

Study case: Fig. 1 shows the quantity of components for the monitor under analysis, where capacitors and resistors represent more than the 80% of the components in the product.

Temperature mission profile has a direct impact in the components failure rate. Failure rate calculation for some components is dependent on the stress generated by temperature. As temperature increase, the failure rate increase, therefore reliability decrease. Additionally, failure

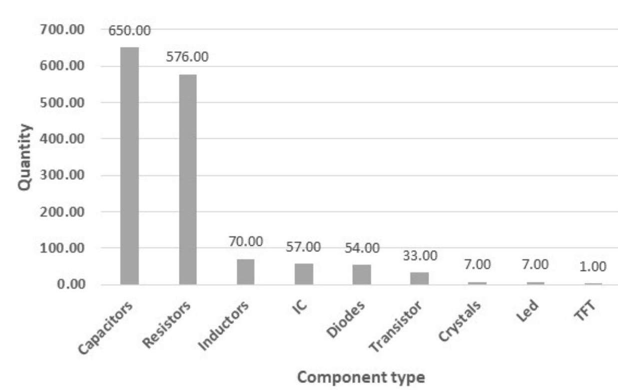

Figure 1. Components distribution by type.
Source: The author, 2024.

Table 2.
Temperature mission profile

i	Ambient temperature (°C) T	% of expected active life length $\%L_i$	Tau τ_i
1	-30	0.0001%	0.00000
2	-25	0.0083%	0.00003
3	-20	0.0339%	0.00013
4	-15	0.1858%	0.00073
5	-10	0.5918%	0.00232
6	-5	3.2056%	0.01256
7	0	7.1742%	0.02811
8	5	12.4835%	0.04891
9	10	12.0191%	0.04709
10	15	17.4888%	0.06852
11	20	18.0311%	0.07064
12	25	14.7121%	0.05764
13	30	8.3714%	0.03280
14	35	4.3508%	0.01705
15	40	1.1150%	0.00437
16	45	0.2286%	0.00090
	Total	100%	0.39178

Source: The author, 2024.

rate will be lower if the distribution of the percentage of expected active life length is centered on the mean ambient temperature. If expected active life length is skewed on high temperatures, it will represent a higher failure rate.

Study case: Table 2 is the temperature mission profile for the monitor under analysis. Monitor is expected to operate on environments between -30°C to 45°C, where the 75% of the operating time is concentrated between 5°C to 25°C.

Life profile is the factor used at the end of the analysis and represents the estimated operation time (in hours) of the product when it works in the field. Reliability prediction will be calculated by using the total failure rate and the estimated operation time as seen on section 3.4.

Study case: Table 3 is the life profile for the monitor, where it is designed to operate 10 years, for a total of 34,320 hr on operation.

Where Tau is the annual ratio of time for the product in permanent working mode, and based on Table 2 and Table 3 data, is given by

$$\boldsymbol{\tau_i} = \left(\frac{\boldsymbol{T.op.time}}{\boldsymbol{T.op.time + T.non\ op.time}}\right) \boldsymbol{x}\ \%\boldsymbol{L_i} \tag{2}$$

Finally, the schematic and data sheets are used for the correct calculation of the operational parameters to be defined in section 3.3. Schematic is used to define, among other things, component location, operation voltages, relationship with other components, etc. On the other hand,

Table 3.
Life profile

Years of operation	10
Weeks operation per year	52
Days operation per week	6
Hours operation per day	11
Average driving speed [km/h]	45
Operation per year [h]	3,432
Total operation time [h] (t_{op})	34,320
Total non-operation time [h] ($t_{non\ op}$)	53,280

Source: The author, 2024.

Table 4.
Failure rates for resistors

Resistors		λ_{ref} in FIT	θ_1 in °C
Carbon film	≤ 100 kOhm	0.3	55
	> 100 kOhm	1	55
Metal film		0.2	55
Network per resistor element			
	Standard	0.1	55
	Custom design	0.5	55
Metal-oxide		5	55
Wire-bound		5	55
Variable		30	55

Source: Siemens SN 29500 standard, 2016.

data sheets are used to get components key parameter as rated power dissipation (W), maximum temperature (°C), temperature at the break point of the power derating curve (°C), rated voltage (V), etc.

3.2 Components classification

Based on the BOM, types of components need to be identified as seen on Fig. 1. Then, the first step is, depending on the type of component, identify the corresponding part of the SN 29500 standard as per Table 1.

Next, look for the table related to the component and select the classification of the component that best match with the component characteristics. As example for a resistor, each of the 576 resistors that are part of the Monitor shall be classified according to Table 4. This procedure should be repeated for all components based in the corresponding part of the standard SN 29500 and the table related to the component, each type of component has its own table for classification.

Classification will define the reference failure rate (λ_{ref}), the corresponding equation for the failure rate calculation of each component and the constant values to be used in the calculation.

Once that each component has been classified, next step is to apply a conversion from reference to operating conditions as explained in next section.

3.3 Conversion models

Classification of each component define the equation for failure rate calculation, in other word, classification define the corresponding conversion model.

Failure rate for each component should be estimated based on equations from Table 5. Where failure rate is given for a reference failure rate and multiplication factors that represent different types of stresses as temperature. Depending on the type of component and the classification, standard SN 29500 should be reviewed to determine the correct equation, Table 5 shows the general equations for each type of component, but depending on the classification some stress factor may not apply. As example, for Capacitors eq. 4 apply as it is in Table 5. For Resistors and Inductors eq. 4 apply but considering only reference failure rate and temperature dependence factor (π_T). For other passive components only reference failure rate is considered.

Table 5.
Conversion models

Components	Reliability general conversion model	Equation number
Integrated circuits and discrete semiconductors	$\lambda = \lambda_{ref} \times \pi_U \times \pi_T \times \pi_D$	(3)
Passive components	$\lambda = \lambda_{ref} \times \pi_U \times \pi_T \times \pi_Q$	(4)
Relays	$\lambda = \lambda_{ref} \times \pi_L \times \pi_E \times \pi_T \times \pi_K$	(5)
Switches and buttons	$\lambda = \lambda_{ref} \times \pi_L \times \pi_E$	(6)
Signal and pilot lamps	$\lambda = \lambda_{ref} \times \pi_U$	(7)
Contactors	$\lambda = \lambda_{ref} \times \pi_S \times \pi_U \times \pi_I \times \pi_T \times \pi_E$	(8)
Optical components	$\lambda = \lambda_{ref} \times \pi_U \times \pi_T \times \pi_I$	(9)
Protection devices	$\lambda = \lambda_{ref} \times \pi_U \times \pi_I \times \pi_T \times \pi_S \times \pi_E$	(10)

Source: Siemens SN 29500 standard, 2016.

In Table 5, λ is the operating failure rate, λ_{ref} is the reference failure rate, π_U is the voltage dependence factor, π_T is the temperature dependence factor, π_D is the drift sensitivity factor, π_Q is the quality factor, π_L is the load dependence factor, π_E is the environment dependence factor, π_K is the failure criterion factor, π_S is the switching rate factor, and π_I is the current factor.

It is important to mention, that every stress factor (π) is represented by a stress model, and the inputs for the stress model are the constants given by the SN 29500 standard and the operational parameters, that are the factors that the standard is unable to define and need to be calculated based on normal/nominal field operation of the product, i.e. power dissipation of a component.

Model π_T, as example for resistors, is given by Eq. (11)

$$\boldsymbol{\pi_T} = \frac{\boldsymbol{A\, x\, exp(Ea_1\, x\, z) + (1-A)\, x\, exp(Ea_2\, x\, z)}}{\boldsymbol{A\, x\, exp(Ea_1\, x\, z_{ref}) + (1-A)\, x\, exp(Ea_2\, x\, z_{ref})}} \quad (11)$$

With

$$\boldsymbol{z = 11605\, x \left(\frac{1}{\theta_{U,ref}+273} - \frac{1}{\theta_2+273}\right) in \frac{1}{eV}} \quad (12)$$

Where

$$\boldsymbol{\theta_2 = \theta_U + \Delta\theta \;\; in}\ ^{\circ}\mathrm{C} \quad (13)$$

$$\boldsymbol{\Delta\theta = P + R_{th}} \quad (14)$$

and

$$\boldsymbol{z_{ref} = 11605\, x \left(\frac{1}{\theta_{U,ref}+273} - \frac{1}{\theta_1+273}\right) in \frac{1}{eV}} \quad (15)$$

where A, Ea_1 and Ea_2 are constants given by the standard, θ_1 is the average reference surface temperature in °C from Table 4 and θ_2 is the average actual surface temperature. Then, θ_2 is a key parameter, because the field calculations will be reflected in it. θ_2 is dependent on θ_U, that is the average actual ambient temperature, and this value comes from the mission temperature profile. $\Delta\theta$ represents the temperature rise due to self-heating of the component and is given by the thermal resistance (R_{th}) in K/W and the operating power dissipation (P) in watts (need to be calculated).

Similar process must be repeated for the component corresponding stress factor, where elements as the operating power dissipation (P), operating voltage (U), must be calculated, and the elements as rated power dissipation (P_{max}), maximum temperature (θ_{max}), temperature at the break point of the power derating curve (θ_{br}) must be consulted on components data sheets, as part of the inputs for the analysis.

3.4 Failure rate

Failure rate is the number of failures per unit time that can be expected to occur for the product and is denoted by λ. Calculations for failure rate in the SN 29500 standard are given in Failure in Time (FIT), that represents one failure per 10^9 component hours. Then, FIT calculation for each component will be dependent on the temperature mission profile, the corresponding conversion model and the applicable operational parameters, where the calculation for each component is given by

$$\lambda_{comp} = \frac{\sum_{i=1}^{n}(\lambda_i\; x\; \%L_i)}{\tau_{total}} \quad (16)$$

Study case: Table 6 shows the process to calculate the component failure rate where a resistor has been taken as example. Resistor under analysis has been classified, according to Table 4, as a "Metal oxide" resistor, then conversion model is given by $\lambda = \lambda_{ref} \times \pi_T$. For the application of the conversion model, it is considered that $\Delta\theta$ is not significant (equal zero), this due to measurements in the printed circuit board (PCB) while operating.

Once that failure rate (in FIT) has been calculated for each mission profile temperature from Table 2, eq. 16 is applied, then, from Table 6, FIT value for the resistor under analysis is λ_{comp} = 0.4044 / 0.3918 = 1.0322. This process must be followed for each single electronic component.

Table 6.
FIT value for a resistor

i	Ambient temperature (°C) T	% of expected active life length $\%L_i$	Tau τ_i	FIT λ_i	λ_i x $\%L_i$
1	-30	0.0001%	0.00000	0.2816	0.0000
2	-25	0.0083%	0.00003	0.3292	0.0000
3	-20	0.0339%	0.00013	0.3828	0.0000
4	-15	0.1858%	0.00073	0.4428	0.0003
5	-10	0.5918%	0.00232	0.5099	0.0012
6	-5	3.2056%	0.01256	0.5847	0.0073
7	0	7.1742%	0.02811	0.6679	0.0188
8	5	12.4835%	0.04891	0.7604	0.0372
9	10	12.0191%	0.04709	0.8630	0.0406
10	15	17.4888%	0.06852	0.9770	0.0669
11	20	18.0311%	0.07064	1.1036	0.0780
12	25	14.7121%	0.05764	1.2441	0.0717
13	30	8.3714%	0.03280	1.4005	0.0459
14	35	4.3508%	0.01705	1.5745	0.0268
15	40	1.1150%	0.00437	1.7685	0.0077
16	45	0.2286%	0.00090	1.9851	0.0018
	Total	100%	0.39178		0.4044

Source: The author, 2024.

After completion of above activity, the failure rate of the product is calculated by summing up the failure rates of each component in each category, this is based on the assumption that a failure of any component leads to a system failure

$$\lambda_{sys} = \sum_{i=1}^{n} \lambda_{comp} \quad (17)$$

On the other hand, there are situations where other sources have to be followed to obtain the component FIT value. Situations as:

- Standard SN 29500 defines little operating experience for a specific condition.
- Classification by the SN 29500 does not completely match with the component. This situation is given by new technologies in components that are not included in the last revision of the standard.
- Component supplier already has reliability data.

3.4.1 Manufacturer reliability datasheet

A simple way to obtain reliability data, when available, is to review the components data sheets that can be found on suppliers' portal, sometimes referenced as Reliability or MTBF or FIT estimator.

3.4.2 Accelerated life testing

Accelerated life testing is performed generally by the component supplier, where the failure rate of the component is given by the model

$$\lambda_{comp} = \frac{\chi^2/2(r, CL)}{Device\ hours} \quad (18)$$

where *r* is the number of failures and *CL* is the confidence level. $\chi^2/2$ (r,CL) value can be obtained using Table 7 .

And

$$Device\ hour = sample\ size\ x\ test\ duration\ x\ AF \quad (19)$$

Sample size is the total amount of components under test, test duration is the sum of test time of all components, and AF is the acceleration factor that is given by the Hallberg-Peck model

$$AF = AT\ x\ AH \quad (20)$$

where

$$AT = e^{\frac{Ea}{k}\left(\frac{1}{K_n} - \frac{1}{Ks}\right)} \quad (21)$$

and

$$AH = \left(\frac{RH_s}{RH_n}\right)^m \quad (22)$$

Table 7.
χ2/2 (r,CL)

Failures	Confidence level (%)			
	50	60	90	95
0	0.6	0.93	2.31	2.96
1	1.68	2	3.89	4.67
2	2.67	3.08	5.3	6.21
3	3.67	4.17	6.7	7.69
4	4.67	5.24	8	9.09
6	5.67	6.25	9.25	10.42
7	6.67	7.27	10.55	11.76
8	7.67	8.33	11.75	13.16
9	8.67	9.35	13	14.3
10	9.67	10.42	14.2	15.63

Source: Vishay, 2008

AT is the Arrhenius model, *Ea* is the activation energy in eV, *k* is the Boltzman constant, *Kn* is the reference temperature, *Ks* is the test temperature. *AH* is the Humidity model, *RHn* is the reference humidity, *RHs* is the test humidity and *m* is the humidity acceleration factor.

3.4.3 Field data

Some components have not data from testing to determine the failure rate, but instead, there is field warranty data to estimate it. Then, failure rate, based on exponential distribution, is obtained as:

$$F(t) = 1 - e^{-\lambda t} \quad (23)$$

then

$$\lambda = -\left[\frac{ln(1 - F(t))}{t}\right] \quad (24)$$

where

$$F(t) = \frac{Functional\ field\ faults}{Produced\ samples} \quad (25)$$

and

$$t = \frac{Operating\ time\ per\ day\ (hr)}{Operation\ days} \quad (26)$$

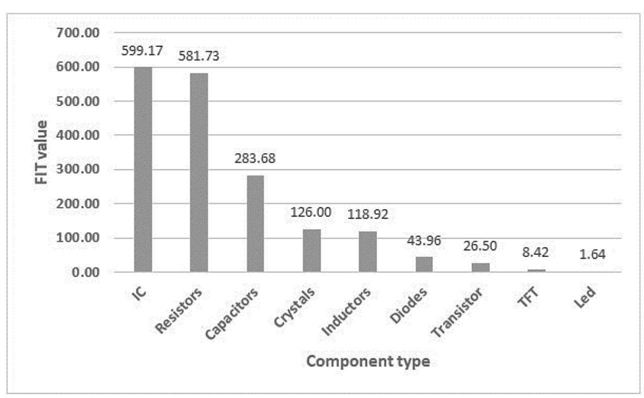

Figure 2. FIT values distribution by component type.

Source: The author, 2024.

Study case: Monitor FIT values distribution by component type is shown in Fig. 2. Total FIT value for the monitor is FIT = 1790.03, where the ICs, resistors and capacitors represents the 80% of the FIT value.

Finally, FIT value for the system in conjunction with the life profile will result in the system reliability as explained in next section.

3.5 Reliability prediction

For reliability prediction based on SN 29500, the failure rate is assumed to be a constant, then the distribution of the failure time is exponential. In this way, the reliability for the system is given by:

$$\boldsymbol{R(t) = e^{-\lambda_{sys}\, x\, t_{op}}} \quad (27)$$

where λ_{sys} is the system failure rate as per sec. 3.4 and t_{op} is the total operation time from Life profile on Table 2.

Study case: Reliability for monitor is given by the exponential distribution, λ_{sys} = 1790.03 and total operation time t_{op} = 34,320 hr. Then, Table 8 summarize calculations for reliability based on eq. 27.

Table 8.
Reliability prediction

Parameter	Value
FITs	1,790.03
Lambda (λ)	1.790E-06
MTTF=1/λ	558,650.25
t_{op}	34320
$\lambda * t_{op}$	6.14E-02
Reliability=e^(-λt)	0.9404
Unreliability = 1-Reliability	0.0596

Source: The author, 2024.

After analysis is completed, it can be concluded that reliability for the system is 94.04%.

4 Conclusions

Reliability prediction is a useful tool on automotive industry that can be used since the beginning of any product design, were the calculation of a reliability value will provide basis to define if a target for the project is met, if a design is better than other one or simply, to evaluate any design improvement to be made.

For reliability prediction based on Siemens SN 29500 standard, this paper provides a guide for practitioners with valuable information for the implementation when it is known that a product is subjected to a variable and changing environment during its useful life.

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