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Predicting the Reliability of Electronic Circuits

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Predicting the Reliability of Electronic Circuits

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Abstract

Procedures to predict the reliability of electrical circuits are discussed. Three cases are introduced and discussed. In Case 1, an analyst predicts the probability of any failure in the intended relations between circuit inputs and circuit outputs. In Case 2, an analyst predicts the probability that specified unintended outputs would occur. In Case 3, an analyst considers coupling between circuits. Logic models are given for the three cases, and sources of failure probabilities of components are mentioned. Methods of analysis are given, software tools are mentioned, and recommendations for presentation and review of results are discussed.

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Introduction

Part of the work assigned to reliability specialists is the prediction of the reliability of electronic circuits and assemblies. There are requests for predictions of the probability that a circuit will work as intended and for predictions that a circuit might provide incorrect, unintended, or unsafe outputs. Developers of firing sets for weapons need predictions of the probability that their firing sets will provide current to fire detonators. Designers of telemetry circuits need predictions of the probability that a circuit will provide a misleading output. This report discusses the methodologies used to calculate predictions of failure probability from circuit designs.

When asked for a prediction of the reliability of an electronic circuit, an analyst must resolve at least four issues:

(1) What constitutes success and what constitutes failure.

(2) How to construct a failure probability model of the circuit, with circuit failure represented as the logical outcome of underlying failure events.

(3) How to assign failure probabilities to the underlying events in the model.

(4) How to obtain and review estimates of failure probability once a model has been constructed and component failure probabilities have been obtained.

These four issues are the topics of this report.

Types of Failures

Three types of failure, arbitrarily called Case 1, Case 2, and Case 3, are defined because they require somewhat different models and analyses.

Case 1 usually applies when the analyst is asked to estimate the probability that a circuit will not perform its intended function when given proper inputs. Case 1 failure occurs if the circuit outputs do not respond as intended to changes in circuit inputs, but the circuit failure does not adversely affect other circuits. Failures that adversely affect other circuits are considered in Case 3. As an example of Case 1, consider the simple series connection of a power source, a switch, and a light bulb shown in Figure 1. Input to the circuit is movement of the switch handle, and output is light from the bulb. Circuit success occurs if, when the source supplies power within specified limits, the light goes on when the switch is closed and goes off when the switch is opened. Failure occurs when the source supplies power within specified limits, but either the light does not go on when the switch is closed or it does not go off when the switch is opened. Note the need to specify the presence of power.

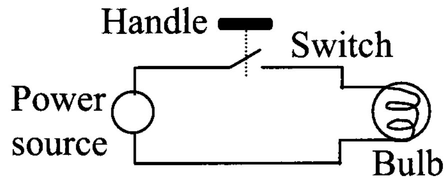

Figure 1. A simple circuit with a power source, a switch, and light bulb is shown.

Case 2 usually applies when the analyst is asked to estimate the probability that a circuit will have a premature or unsafe response. Case 2 failure occurs if the circuit output is not as intended for some, but not necessarily all, inputs and the circuit does not draw so much current as to affect other circuits. For example, Case 2 would apply if the task were to estimate the probability that an instrumentation circuit would provide incorrect indication that an event has occurred. Consider again the simple circuit shown in Figure 1, but now suppose that failure is defined to be *light on when the switch is open and the power source is supplying power.* Failure would occur if the switch were stuck in the closed position, if a conductor bridged the switch contacts, or if there were an unintended connection between the light and the source of power.

Case 2 failures are often a subset of all failures. However, sometimes the set of possible failures is increased to include unintentional contact between conductors or contact with conductors external to the circuit. For example, such failures are often included in safety analyses.

Case 3 applies if a fault in the circuit under study adversely affects operation of other circuits. Coupling could occur in many ways. For example, a fault could result in an overload on system power supplies or an overload on a system clock. Let a night-light and an alarm clock be plugged into the same household circuit. Failure of the night-light as a short circuit would lead to opening of a fuse or circuit breaker and loss of power to the alarm clock. An analyst should determine if coupling between circuits is possible and if it is important. A Case 3 analysis is often complex because of the coupling between circuits. Such analyses are not discussed further in this report.

Every failure does not fit perfectly into one of these three categories. Even so, they prove useful. It is not unusual during an analysis to refine definitions of faults and add faults that were overlooked.

Models

This section discusses the translation from descriptions of an electric circuit to reliability models. Electric circuits are described by lists of parts and by schematics that show how the parts are interconnected. Sometimes the circuit designer specifies physical layout, but often this is left to the discretion of assemblers. The procedure used to go from a parts list or a schematic to a reliability model depends on whether the analyst is modeling Case 1, Case 2, or Case 3 failure types. Consider Case 1 first.

Case 1 is often the easiest to model. The author's experience and that of many other analysts is that for most circuits there will be a Case 1 failure, if any part fails.[1] This does not mean that failure will occur if any resistor or other component has a value slightly different from that shown on the schematic. Circuits are designed to work with components that have values in expected ranges. However, circuit failure in the Case 1 sense is likely if any component has a value far from the specified value. Open circuits and short circuits are far from the expected value for most components. The logic model for Case 1 is the Inclusive OR of the failure of every component in the circuit. To the extent that the model is correct and that component failures are independent, the Case 1 failure probability for a circuit is given by equation 1 in which f_c is the failure probability for a circuit made up of m components, each with failure probabilities f_i:

$$f_c = 1 - \prod_{i=1}^{m} (1 - f_i) \qquad \text{Eq.1}$$

If all products of two or more f_i's are small compared to any f_i, then Equation 1 may written as

$$f_c \cong \sum_{i=1}^{m} f_i \qquad \text{Eq. 2}$$

The *m components* include all items that the analyst decides belong in the model. For example, the analyst may include interconnect wires or account for interconnects otherwise. Sometimes it is necessary to take into account failure of solder joints, failure of substrates, and failure due to unintended connections. The first of these is often included in the failure probabilities for piece parts, the second may or may not be a significant contributor to the failure probability, and the third is not usually considered in Case 1 analyses. Substrate breakage can be a significant contributor to failure for hybrid microcircuits that are assembled on ceramic substrates and that are subjected to significant shock or vibration, but may not be a significant failure mode for circuits on resin-laminate circuit boards. In each instance, the analyst must decide what failure modes to include in the model. The assumption that components fail independently of each other is not restrictive because, in the model, the first failure of any component results in circuit failure. It is frequently the case that failure of one component will lead to failure of other components. However, the fact that a string of failures occurs does not change the fact that the circuit failed when the first failure occurred.

Implicit in the use of a logical OR failure model is the assumption that the actual electrical circuit and the mechanical layout of parts are unimportant except as they affect the failure probabilities of individual components. Also implicit are the assumptions that

[1] Remember that Case 1 failure occurs if even one of the intended relationships between inputs and outputs fails.

there are no redundant parts or unnecessary parts. These latter two assumptions are usually justified because designers of electrical circuits do not usually insert redundant parts to improve circuit reliability, nor do they put in unnecessary parts. However, exceptions occur. The author analyzed safety-critical circuits in which two voltage-limiting diodes were connected in parallel solely to increase the protection against over voltage and a nuclear weapon component in which the two relays were connected in parallel to increase the likelihood that power would be supplied to a circuit. The author has also seen circuits used in Sandia-designed equipment that contain parts that are unnecessary for weapon function, but are needed for monitoring. The circuit shown in Figure 2 illustrates the use of component for monitoring. The circuit is the same as the one shown in Figure 1 except that a resistor buffered test port has been added. The resistor is not needed for the primary function of the circuit, which is to turn on and turn off the light. The circuit will perform these functions independent of the value of the monitor resistor if the test port terminates in an open circuit. However, if the functions of the circuit were expanded to include the monitor function, then an open circuit or high resistance at the monitor resistor would lead to Case 1 failure. The example illustrates the need for preciseness in the definition of circuit function and circuit failure.

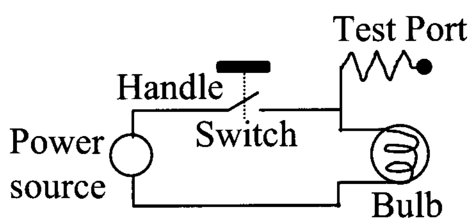

Figure 2. The simple circuit shown in Figure 1 with a test port added is shown.

For illustration, suppose the task is to estimate the probability of a Case 1 failure of a circuit for which the list of parts shows three capacitors of the same type, four resistors of the same type, two field effect transistors of the same type, and one transformer. A Case 1 reliability analysis might be done as shown in Table 1. It is common practice to use C to indicate a capacitor, Q to indicate a transistor, R to indicate a resistor, and X to indicate a transformer. The determination of failure rates and failure probabilities is discussed later in this report.

Table 1. Example of a Case 1 Reliability Analysis. It is assumed that Eq. 2 applies.

Component	Number	Failure Probability	Contribution
Capacitor	3	f_C	$3f_C$
Resistor	4	f_R	$4f_R$
Transformer	1	f_X	$1f_X$
Transistor	2	f_Q	$2f_Q$
Total Failure Probability			$3f_C+4f_R+f_X+2f_Q$

Case 2 failure occurs when an output is incorrect in some specified way. For example, the voltage at an output may be stuck high, or an instrumentation circuit may indicate that an event occurred without the intended inputs from sensors. Many times, the Case 2 failure of interest is a member of the set of events that defines Case 1 failure. For the circuit shown in Figure 1, a Case 2 failure might be *light on, independent of switch position*. If the Case 2 failure is included in the set of Case 1 failures, the logical OR model with all parts considered will provide an upper bound on the failure rate if other failure modes do not need to be considered. If the calculated bound is acceptable, there may be no reason to do a more detailed analysis. More analysis will be required if the bound is unacceptably large or if additional failure modes need to be considered.

The possibility of other failure modes is a particular issue in analyses to determine the probability of unsafe response. Unsafe response might be the result of component failures, but it might also be the result of short circuits between wiring or due to other faults. Unintended interconnection of wiring is not usually included in models for Case 1 because the contribution to failure probability is usually much less than other contributions. However, such a fault may be major contributor to the probability that a circuit provides an unsafe or unintended output.

The reliability model for a Case 3 failure has to take into account the possibility that failure in one circuit will cause failure in other circuits. Models for such failure are specific to each system and can be quite complex. They are not covered further in this report.

Application, Environment, and Operating Conditions

The analyst has to take into account thermal, mechanical, and electrical stressors that strongly affect the life of components. For most electrical components, life decreases rapidly as operating temperature increases. For example, the life of silicon semiconductor components decreases by about a factor of ten for each 27 C increase in junction temperature. It is not enough to know the ambient temperature. For semiconductor components it is necessary to know or to estimate junction temperature. For most other components, it will be adequate to know or to estimate internal temperature. For circuits in dormant storage, junction temperatures and internal temperatures will be the same as the ambient temperature unless heating or cooling is present. For operating circuits, junction temperature or internal temperature will be higher than the temperature inside a circuit enclosure, which will itself be higher than the ambient temperature. The total difference between ambient temperature and junction or internal temperature can exceed 100 °C for components that dissipate large amounts of power.

Life of solder joints decreases due to metal fatigue as the severity and frequency of temperature cycling increase. At the time this report was written, R. Wavrik in the Advanced Packaging Department (1745) was using software to evaluate thermal-mechanical stresses on solder joints. Life of other components, for example ceramic circuit boards, may be shortened by thermo-mechanical stresses.

The lifetime of plastic encapsulated parts can be much lower at high relative humidity than at low relative humidity. This is particularly true if high humidity occurs in conjunction with temperature cycling.

Vibration and other mechanical stressors such as shock can reduce circuit life. The PRISM© (Reference 3) software tool allows specification of vibration directly through statement of maximum acceleration or indirectly through specification of an application. Applications range from ground-fixed for which the vibration level is quite low to rotary wing aircraft for which the vibration level is quite high.

Applied voltage is an important electrical stressor. For example, the life of capacitors decreases rapidly from the nominal value for applied voltage equal to or less than 50% of rated voltage to much less than the nominal value for applied voltage equal to rated voltage. PRISM© allows the specification of operating voltage for capacitors. The life of other components also decreases as operating voltage approaches rated values.

Rarely will an analyst have complete information about stressors. Often voltage levels can be determined from circuit schematics and vibration levels can be estimated for the application. Often, it will difficult to get good information about junction temperatures and internal temperatures. If little information is available, it may be necessary to make credible assumptions about temperatures and calculate a range of reliabilities.

Sources of Failure Rate and Failure Probability Information

There are at least four sources of data on failure rate or failure probability (i.e., a Sandia database for parts used in stockpile nuclear weapons, commercial databases, information from manufacturers, and models). Attributes, advantages, and limitations of these sources of information are discussed in this section.

It is desirable to use failure rate data from components and environments that are as similar as possible to the actual components and anticipated environments. Rarely, if ever, are data available for the same component in an environment identical to the anticipated environment. Therefore, the analyst almost always has to find failure rate information for components as similar as possible to those in a circuit to be analyzed. Then the rates must be adjusted to account for differences between the parts and operating conditions for which there is information and the parts and operating conditions of interest.

Sandia Nuclear Weapon Stockpile Database

The reliability assessment department at Sandia maintains databases on the failure probabilities of electronic and other components that are or were in stockpile nuclear weapons. Table 2 shows the probability that the component will fail in a twenty-year stockpile period for several electronic components. The data are presented in this way because there have not been enough failures to determine failure rates. In fact, for many components (e.g., resistors), no failures have been observed. For such components, the value given in Table 2 is the 50% upper confidence limit for the failure probability given zero failures in some number of component-weapon lifetimes. For example, the failure probability for resistors was obtained from the observation of no failure in approximately 1.85E6 resistor – 20 year weapon life times.

Table 2. Failure probabilities from the Sandia database

Component	Probability of failure in 20 years
Cable	1E-6 per strand
Capacitor, low voltage	4E-5
Capacitor, solid tantalum	6E-5
Diode	
Beam lead	9.9E-6
Other	1.1E-5
Filter	8E-5 + 1E-6 per connector-cable interface
Inductor or Transformer	2E-4
Integrated circuit	
Large scale	8.8E-4
Memory	8.6E-4
Small scale	4.1E-5
Resistor	5.4E-7
Transistor	
Beam lead	9E-6
Other	1.2E-4

Similar assessments are made and updated for many other nuclear weapon components. The data shown in Table 2 are useful in the analysis of circuits that will go through the sequence of manufacture, acceptance, storage, and possibly surveillance testing experienced by components in stockpile nuclear weapons. During manufacture and acceptance, weapon components are operated for a few hours to a few tens of hours. Once a weapon is accepted, components in it may operate continuously; intermittently, if the weapon is selected for surveillance tests; for a short period if the weapon is used as intended; or never. Most of the information used to calculate the failure probabilities shown in Table 2 was taken from tests on circuits and assemblies that operated during manufacture and acceptance testing, were in dormant storage for years, and then were energized for seconds or minutes.

If the task is to calculate the reliability for a time much different than twenty years, the analyst will have to estimate the failure probability for the time of interest. One way to obtain such an estimate is to assume that the failure probability can be converted to a rate by dividing by twenty years or by an equivalent number of hours or other measure of time. However, as was stated above, the data from which the values in Table 2 were calculated do not support the calculation of rates. One way out of this limitation is discussed below.

In a paper published in December of 1981, George Merren, at the time a manager in the Sandia reliability organization, proposed that twenty-year failure probabilities could be split into a part that was independent of time and a part that was proportional to time (Reference 1). If Merren's proposal is accepted, the failure probability for a time other than twenty years is the sum of 25% of the twenty-year value and 75 % of the twenty-year value adjusted by the ratio of the time of interest to twenty years. The method is reasonable in that it yields lower failure probabilities for short missions but avoids the very low failure probabilities that arise if values shown in Table 2 are simply scaled by ratio of mission duration to twenty years. Zurn and Bierbaum used Merren's method in their analyses of circuits for telemetry systems for the B61 and W76 programs (Reference 2).

Difficulties arise if the mission duration is very different from twenty years and the mission profile is very different from stockpile.[2] An example will illustrate the difficulties. Suppose the method is used to estimate the failure probability for 52 ten-minute duration missions in one year. Assume further that the failure-determining stresses are not much different during operation than during storage. According to Merren's method, the failure probability for each mission is 0.25 of the 20-year value plus a negligible amount to account for ten minutes of use. Therefore, the failure probability for 52 such missions is slightly more than 13 times (0.25 multiplied by 52) the failure probability for twenty years. This is not a reasonable result given the assumption that stresses during operation are not very different than those experienced during storage. An imaginative analyst could think of ad hoc adjustments to Merren's method that would better fit the situation. Possibilities are not discussed because the example is given only to show that if Merren's method is used, it must be used carefully.

The operating conditions for many systems are very different than the conditions of nuclear weapon storage. Components in commercial, industrial, and military equipment may experience a period of dormant storage after manufacture and before use. However, for most such equipment, the period of dormant storage is short compared to a longer period of utilization during which power is applied intermittently or regularly. Furthermore, circuits in aircraft, particularly those in rotary wing aircraft, operate in an environment in which there is a lot of vibration. Circuits in vehicles, for example in a secure transport vehicle, may experience much more vibration, higher temperatures, and more extreme temperature cycling than circuits in stored weapons. The author knows of no general way to adjust the values in the Sandia database for conditions other than dormant storage.

Reliability Analysis Center Data Bases

The Reliability Analysis Center (RAC)[3] has gathered and analyzed failure data for many military systems and for many conditions of use. Failure rates obtained from the data were once available in Mil-Handbook 217 (Reference 3), but the last update of this

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[2] Merren did not propose using the method for conditions such as are given in the example. Those conditions were chosen to help the reader understand the issue discussed in the text.

[3] Reliability Analysis Center, 201 Mill Street, Rome, NY 13440.

document was done in 1991. Various documents that contain failure rates derived from the data are available from RAC. The results are also available in software reliability analysis tools such as PRISM© (Reference 4) and RELEX (Reference 5).

Table 3. Failure rates and failure probabilities derived from PRISM©. See text for definition of environment, duty cycle, and operating conditions.

Component	Dormant		Operating	
	Rate (hr^{-1})	Prob (20yr)	Rate (hr^{-1})	Prob (20yr)
Capacitor – 0.1 μF Ceramic	8.10E-10	1.4E-04	5.90E-09	1.0E-03
Diode – Gen. Purpose	3.70E-10	6.5E-05	1.60E-09	2.8E-04
Inductor – Fixed Coil	3.70E-09	6.5E-04	3.70E-09	6.5E-04
Resistor – 1/4 W Fixed Carbon	1.10E-09	1.9E-04	2.80E-09	4.9E-04
Transistor – Low Freq., npn	8.90E-09	1.6E-03	1.60E-08	2.8E-03

Failure rates in units of failures per calendar hour and failure probabilities for twenty years of use derived from PRISM© are shown in Table 3. The values were calculated to illustrate the types information that can be obtained from PRISM© and to provide comparison with values from the Sandia database. The data from RAC, including that in PRISM©, allow more specificity about the type of component and the conditions of use than do the data in the Sandia database. For example, there are RAC data for specific types of capacitors, diodes, integrated circuits, resistors, and transistors. There are also data for specific applications, temperatures, duty cycles, and cycles per year. The values shown in Table 3 were all calculated for a ground fixed application. Other possible applications include ground mobile, fixed wing and rotary wing aircraft, spacecraft, missiles, naval, and others. To calculate values for dormant storage, it was assumed that the temperature was 23 °C and that no power was applied. For calculation of values for operation, it was assumed that the ambient temperature was 23 °C, the operating temperature was 50 °C, the duty cycle was 50%, and there were 365 cycles per year.

Note that for the conditions chosen, failure rate for operation is only about a factor of two greater than the failure rate for dormant storage. This has important implications in the prediction of failure rate for a mission in which equipment is turned on for a short period of time, turned off for a relatively long time, and then used for a relatively short time. The failure probability for such a mission would be underestimated if failure during the turned-off time were neglected.

Probabilities of failure during twenty years of dormant storage obtained from the Sandia database and from PRISM© are compared in Table 4. It is seen that the values obtained from the Sandia database are always smaller. For all the components shown, except resistors, the difference is between a factor of 3 and a factor of 13. The difference for resistors is a factor of 350. Factors of 3 to 13 can be explained by the procedures used to define and procure parts for nuclear weapons and the relatively benign conditions of storage. The author knows of no reason why the failure probability for resistors in nuclear weapons should be so much smaller than the failure probability estimated from PRISM©.

Table 4. Failure probabilities for 20 years of dormant storage from PRISM© and from the Sandia database.

Component	PRISM© 20 years of dormant storage	Sandia database 20 years of dormant storage
Capacitor	1.4E-4	4.5E-5
Diode	6.5E-5	1.1E-5
Resistor	1.9E-4	5.4E-7
Transistor	1.6E-3	1.2E-4

Note that the failure rates shown in Table 3 for operation are always larger than the rates for dormant storage. This difference is expected. It has an important implication for an analyst who is tempted to use the Sandia database for a system that will be operated rather than stored. It was pointed out in the previous paragraph that the Sandia database yields lower failure probabilities for dormant storage than does PRISM© for dormant storage. Therefore, use of the Sandia database will result in estimates for operating systems that are quite a bit lower than estimates obtained from PRISM©.

A group from TRW (Reference 6) and a group from Raytheon (Reference 7) have reported comparison of PRISM© failure rate predictions with field failure data. The TRW group reported that the predictions for an automotive circuit were pessimistic by about a factor of two. The Raytheon group reported that predictions for circuits for fixed and rotary wing aircraft were close to slightly low compared to experience. Together the reports increase confidence in the PRISM© methodology.

Manufacturer Data

Data sheets and other literature from manufacturers sometimes contain information on reliability or the results of tests done to evaluate reliability. For example, the information might show that some number of failures were observed when some number of parts, were subjected to an accelerated life test. The use of such information to obtain an estimate of the failure rate at use conditions is outside the scope of this report. It is particularly important to check the reasonableness of an estimated failure rate if zero failures were observed. If no failures were observed, calculation yields an upper bound, not a point estimate of the failure rate. This upper bound can be much larger than the actual failure rate if the number of part-hours in the test was relatively small. Reasonableness can often be evaluated from a comparison of the calculated rate with rates obtained from the Sandia database or from a tool such as PRISM©. Reasonableness means that there are reasons or data to support failure probabilities that make large contributions to the overall failure probability and to support the assignment of significantly different failure probabilities to similar components.

Failure Probabilities from Models

Sometimes a system will contain assemblies for which the analyst cannot find reliability data. One way around the lack of data is to obtain circuit diagrams for the assemblies and calculate Case 1 reliability estimates. Even if a circuit diagram is not available, an analyst may be able to use engineering judgment to estimate what parts are probably in an assembly. For example, many switching power supplies contain a control integrated circuit, at least four rectifier diodes, a transformer, and at least one filter capacitor. Discussion with a power supply designer or reference to a trade magazine might add a few parts. Once an estimated parts list has been constructed, a Case 1 analysis can be performed. Essentially the same process can be used to estimate the failure rate for a new component if something is known or can be assumed about failure modes. The principal failure modes for most semiconductor devices are chip failure, die attach failure, wire bond failure, and package failure. An initial estimate of the failure rate of a new part could be the failure rate of an existing part that has a chip of comparable complexity in a similar package. The rate for the existing part could be multiplied by a factor of up to ten to account for lack of experience in manufacture and use of the new part.

Analysis

Once a reliability model and estimates of failure probabilities are available, a table similar to Table 1, a spreadsheet, or a tool such as PRISM© can be used to estimate the failure probability for a circuit. The author recommends that the results of the analysis be arranged so that it is easy to determine the relative contributions from various components. It is not unusual to find that a few components or a few types of components contribute almost all the failure probability. This is particularly likely if the circuit contains mechanical components (e.g., switches or electro-mechanical components such as relays). Many such components have much higher failure rates than non-mechanical components. The failure probabilities for all components should be re-checked for consistency. This step is particularly important for the components that make the largest contributions to the failure probability.

Table 5 shows the result of applying failure probabilities to the parts list given in Table 1. For this example, the total failure probability is not dominated by a single component. Table 6 shows the components rearranged in order of contribution to the failure probability. The rearrangement suggests that it might be worthwhile to re-check the failure probabilities of transistors, transformers, and capacitors, but that little improvement in the certainty of estimated reliability would result from more attention to the failure probability of resistors. Sometimes insight into the major contributors to failure probability can be gained if similar components are grouped together as was done in Tables 1, 5, and 6. The contribution from transistors would be less obvious if each transistor were listed separately. This is particularly true if there are many similar components in a circuit or system.

Table 5. Case 1 Reliability Analysis Example. Failure probabilities from Table 2.

Component	Number	Failure probability (20 years)	Contribution
Capacitor	3	4E-5	1.2E-4
Resistor	4	5.4E-7	2.2E-6
Transformer	1	2E-4*	2E-4
Transistor	2	1.2E-4	2.4E-4
Total failure probability (20 yr)			**5.4E-4**

* The failure rate for a transformer is taken to be the same as that of an inductor.

Table 6. The information in Table 5 rearranged by contribution to the failure probability.

Component	Number	Failure probability (20 years)	Contribution
Transistor	2	1.2E-4	2.4E-4
Transformer	1	2E-4	2E-4
Capacitor	3	4E-5	1.2E-4
Resistor	4	5.4E-7	2.2E-6
Total failure probability (20 years)			**5.4E-4**

If an analyst is fortunate enough to have distributions of failure probabilities, software tools such as Crystal Ball (Reference 8) can be used to obtain predictions of the distribution for the failure probability of a circuit.

Iteration

As a project progresses, additional data on failure rates or failure probabilities may become available. For example, data may become available from accelerated life tests on the components that will be used in a design. Such data may corroborate or refute initial estimates. In either case, use of such data will increase the relevancy of estimates.

Circuit designs may be changed because of shortfalls in the circuit design or because components did not meet expectations for performance, availability, reliability, or some other important characteristic. Particularly significant from a reliability viewpoint would be the use of redundant components to reduce the likelihood of failure. When such changes occur, the analyst will have to decide if a revised estimate of failure probability or of failure rate should be generated.

Summary

Four issues that an analyst must resolve when asked for an estimate of the reliability of an electronic circuit have been discussed. The first is what constitutes circuit success and what constitutes failure. The second is how to construct a reliability model of the circuit. The third is how to obtain failure probabilities for events in the model. The fourth is how to calculate and review estimates of system reliability and how to display results.

It was shown that the definition of failure, the type of analysis required, and the type of reliability model used are related. Three types of failure, identified as Cases 1 through 3, were defined. Case 1 usually applies when the analyst is asked to estimate the probability that a circuit will perform its intended function. The logic model for Case 1 is the Inclusive OR of the failure of every component in the circuit. Case 2 usually applies when the analyst is asked to estimate the probability that a circuit will have some specified incorrect or unintended output. If the failure of interest is in the set of Case 1 failures, the Case 1 model may be adequate. However, it is often necessary to prepare a model that is limited to the failures of interest but that includes failure modes not always included in a Case 1 analysis. A short circuit between internal wires is an example of such a failure. Case 3 applies if a fault in the circuit under consideration causes other circuits to fail. The reliability model for Case 3 failure has to take into account the possibility that failure in one circuit will cause failure in other circuits. Models for such failures are specific to each system and can be quite complex.

Sources of failure rate or failure probability values were given. Also given were methods that can be used to construct an estimate of failure probability when values are not available. Ways to calculate estimates of circuit reliability from a model and estimates of component failure probabilities were described. The analyst must review all results for reasonableness. It is useful to sort results in descending order of contribution to failure probability so that the major contributors can be identified. The review may show a need for more work on the model or on estimates of component failure probabilities.

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