DragonWave Failure Rate and MTBF Prediction Methodology

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Introduction

Project Definition

This document provides details of failure rate prediction work performed by DragonWave, Inc. It includes the scope of the work, the assumptions, and a Methodology used.

The prediction is performed in accordance with Telcordia standard SR-332 Issue 2 based on supplied component temperatures and stresses. Other environmental factors have been determined based on information supplied by DragonWave design and mechanical teams.

Acronyms

BOM	Bill of Materials
HC+	Horizon Compact+
HQ	Horizon Quantum
FITs	Failures per 109 hours
IDU	Indoor Unit
ODU	Outdoor Unit
MRP	Material Resources Planning
MTBF	Mean Time Between Failures

References

[1] Reliability Prediction Procedure for Electronic Equipment, SR-332, Issue 2, Sept 2006, Telcordia Technologies
[2] ETSI Standard, ETS 300 019-1-4: Equipment Engineering (EE); Environmental conditions and environmental test for telecommunications equipment.
[3] GaAs MMIC Reliability Assurance Guideline for Space Applications; Sammy Kayali, George Ponchak; Roland Shaw (Available at: http://parts.jpl.nasa.gov/mmic/contents.htm)

Prediction Methodology

This failure rate prediction is performed according to Telcordia Standard, SR-332, "Reliability Prediction Procedure for Electronic Equipment." SR-332 was originally created based on the procedures in MIL-STD-217, but accounting for the failure rates and environments typical in telecommunication applications rather than military. This section provides some details of SR-332 relevant to the current activity.

Prediction calculation vs. Actual field data

The results published in the reports are prediction values using the parts count + lab data method. DragonWave has historically seen actual field data performance that is 2-3 times better than the predicted values that we calculated with the prediction methods shown here in the report tables.

Parts Count and Part Count with Lab Data Method

The Parts Count Method from SR-332 is used which assumes that the failure rate of a product is equal to the sum of the failure rates of the individual components that make up the product and can be expressed as:

$$\lambda_{PC} = \pi_E \cdot \sum_{i=1}^{n} \lambda_{SS}$$

Where

n is the number of different components in the unit.

π_E is the environmental factor based on the general environment in which the unit is installed.

The steady state failure rates for components are determined using the Black Box Method from SR-332 where the steady-state failure rate for the i^{th} component is based on a generic failure rate for the component multiplied by factors accounting for the component's quality and it's application. The steady-state failure rate is calculated as:

$$\lambda_{SS_i} = \lambda_{G\,i} \cdot \pi_{Q_i} \cdot \pi_{S_i} \cdot \pi_{T_i}$$

Where

$\lambda_{G\,i}$ is the generic steady-state failure rate for the i^{th} component

π_{Q_i} is the Quality Factor for the i^{th} component

π_{S_i} is the electrical Stress Factor for the i^{th} component

π_{T_i} is the Temperature Factor for the i^{th} component

The generic failure rate and the various factors are discussed in the following sections.

Two techniques are available for using laboratory data to predict steady-state device failure rate. The technique to use depends on whether the devices in the laboratory test were burned-in or not. In either case, the mean and standard deviation of the device steady-state failure rate are, respectively,

$$\lambda SSi = \frac{\lambda BBi\ (2+n)}{A} \text{ and } \sigma SSi = \frac{\lambda BBi\ \sqrt{2+n}}{A}$$

where n is the number of device failures in the laboratory test. The techniques differ only in the calculation of A. This prediction technique is based on "A Bayes Procedure for Combining Black Box Estimates and Laboratory Tests." This method may be applied using laboratory data for a similar counterpart to the subject device of the prediction. In determining whether a device from a laboratory test is a suitable counterpart for the subject device, the similarity of the wafer process, device materials, assembly process, transistor structure, and external packaging should be considered.

Component Reliability

What Telcordia defines as the generic steady-state failure rate is the failure rate of a device of the typical quality used by most telecommunications providers and under typical conditions in a telecommunications Central Office environment. This is a method of normalizing all components to a fixed set of conditions. As an example, it assumes operation at 40 °C with 50% of the maximum electrical load. Operation under other conditions is accounted for by the multiplying factors.

The generic steady-state failure rates are based to a large degree on field data in telecommunications environments, and so take into account factors such as the typical design and manufacturing quality of telecommunications equipment providers. For this reason, elements such as circuit boards and solder joints are not assigned failure rates, as their contribution is assumed to be reflected in the component failure rates.

Stating a failure rate prediction implies a certain mathematical level of confidence. The Telcordia steady-state failure rates are based on a 60% upper confidence level. This implies that there is at least a 60% chance that the actual failure rates will be less than the prediction.

Environmental Factor

The Environmental Factor takes into account the conditions into which the equipment is deployed. For this reason, a single value for the environmental factor applies to the entire calculation. Harsher environments have higher multiplying factors. Details can be found in Telcordia, SR-332, Table 9-5. Briefly, the environments are:

Ground, Fixed, Controlled
Nearly zero environmental stress - typical of Central Office or environmentally controlled shelters, vaults, or customer premise areas.

Ground, Fixed, Uncontrolled
Some environmental stress – typical of man-holes, poles, customer premise areas subject to shock, vibration or environmental variation.

Ground Mobile
Conditions more severe than Ground, Fixed, typically due to shock and vibration – typical of mobile phones, portable operating equipment, test equipment.

Airborne, Commercial
Conditions more severe than Ground, Fixed, typically due to pressure, temperature, shock and vibration - typical of the passenger compartment of commercial aircraft.

Space-based, Commercial
Low earth orbit with conditions as for Airborne, Commercial, but with no maintenance – typical of commercial communications satellites.

Quality Factor

The Quality Factor, represented by π_Q, reflects the quality of each component being used in a product. One of four levels (0, I, II and III) are assigned based on the quality of the component supplier and the procedures in place to ensure the quality of components received. Note that different component types in a design may have different quality levels. Telcordia, SR-332, Table 9-4 should be consulted for details. Following are a few key elements of each level:

Quality Level 0

Commercial-grade or re-worked components with no qualification or lot-to-lot control. Steps must be taken to ensure they are compatible with the application.

Quality Level I

Commercial-grade components without thorough qualification or lot-to-lot control. Steps must be taken to ensure they are compatible with the application and with manufacturing processes. An effective feedback and corrective action system must be in place for manufacturing and in the field.

Quality Level II

Requirements of Quality Level I, plus

- purchase specifications must identify important component characteristics.
- components and their manufacturers must be qualified and identified on approved parts/manufacturers lists.
- lot-to-lot controls with adequate AQL/DPM levels must be in place by equipment manufacturer of device supplier.

Quality Level III

Requirements of Quality Level II, plus

- periodic re-qualification of device families
- 100% screening (may be reduced to an audit if warranted)
- continuous improvement programs in place at device and equipment manufacturers

The usual expectation is that most telecommunications equipment providers should be operating at Quality Level II – a fact which is reflected in the multiplying factor for that level being 1.0. Other Quality Levels have higher or lower multipliers as appropriate.

Stress Factor - Electrical

The Electrical Stress Factor is based on the percentage of a component's maximum electrical rating under which it operates. The generic steady-state failure rates are normalized to an electrical stress factor of 50%, corresponding to a multiplier of 1.0.

The type of electrical stress which is relevant (power, voltage, current) depends on the type of component. For instance, capacitor electrical stress is dependent on voltage, whereas diode electrical stress is typically based on the applied current.

Electrical stress affects the failure rate of different components to differing degrees depending on the type of component – though they all follow an exponential curve. The following Figure 1 graph shows how electrical stress affects the failure rate of a few different components:

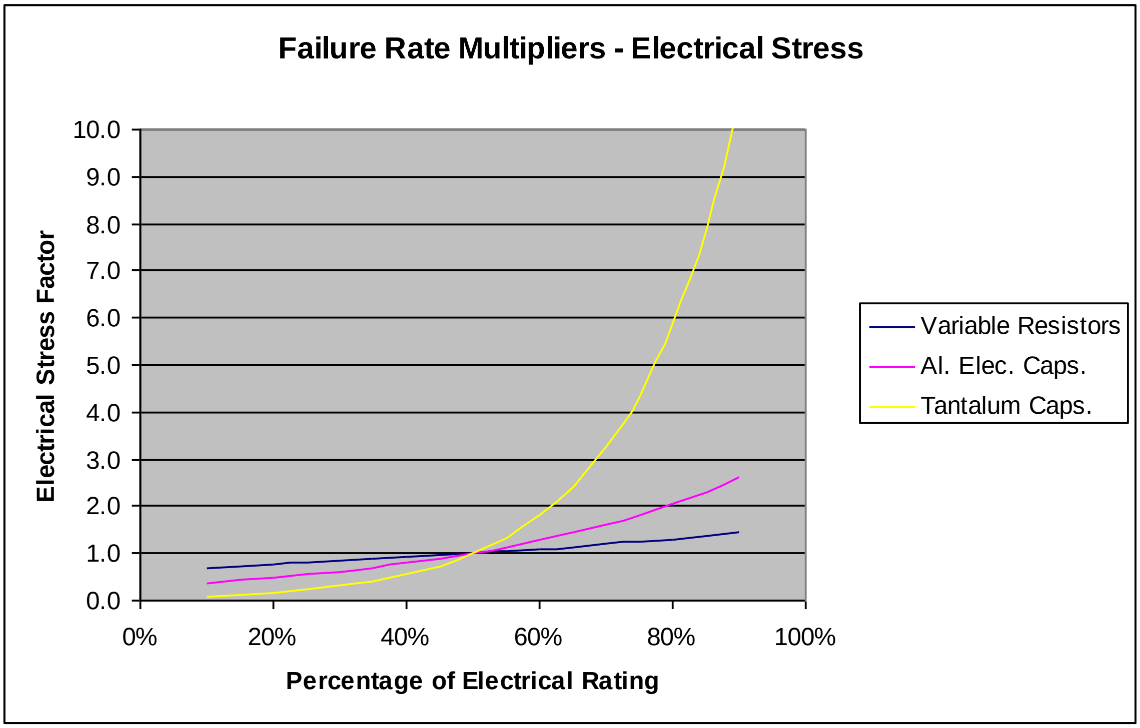

Figure 1 – Electrical Stress

We see that electrical stress has a very large influence on the failure rate of tantalum capacitors and a fairly small influence on variable resistors. Generally, no component should be operated at over 90% of its maximum electrical stress, but the graph shows a further

advantage can be achieved by drastically de-rating certain components to minimize the total failure rate

Temperature Factor

Similar to electrical stress, increasing temperature causes an exponentially increasing failure rate in components. The rate of failure rate increase with temperature is dependent on the type of component.

It should be noted the Telcordia, SR-332 specifies the temperature as being measured ½ inch above the component, and so the thermal resistance of the air as well as air-flow comes into play. The component case temperature provides a more accurate view of the component operating conditions, but this can be related to the air temperature as specified by making a few simple assumptions.

The following Figure 2 graph shows the effect of temperature on a few different components. Note that in this case, the increasing temperature stress affects aluminum electrolytic capacitors much more than it does tantalum capacitors. This is reverse of the case with electrical stress, so each component type must be considered individually when accounting for stress in the design.

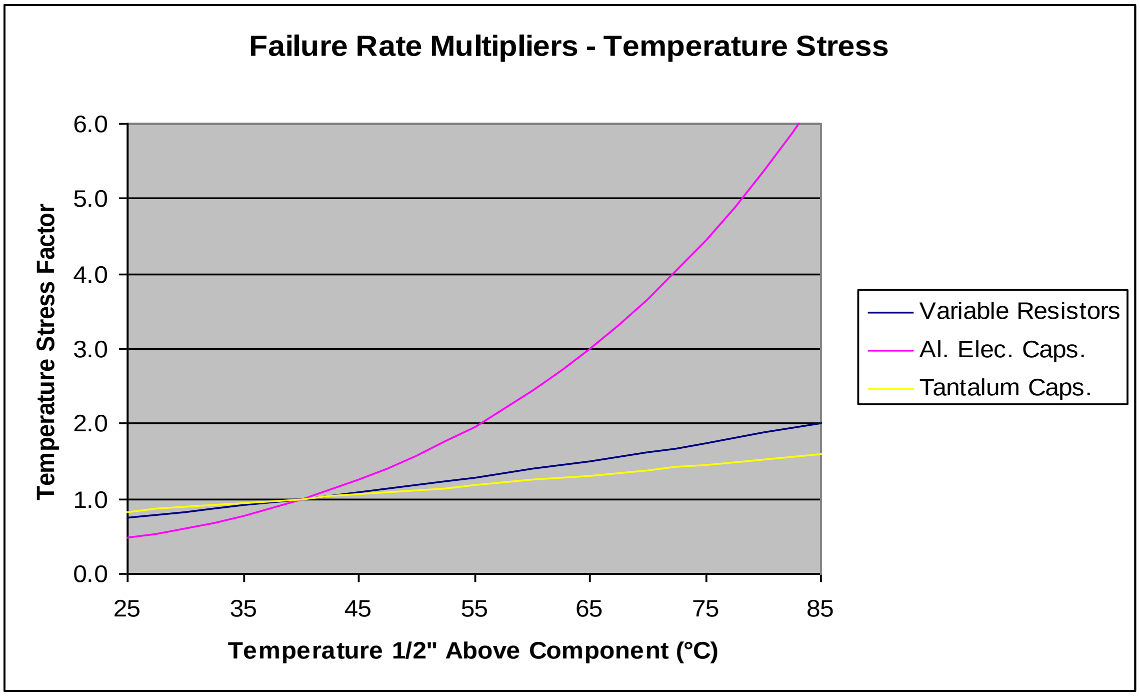

Figure 2 – Temperature Stress

Prediction Assumptions

Quality Level

Telcordia Quality Level II is assumed for all devices included on the BOM. As outlined in Section 9.3, this essentially dictates that there is a qualification program in place for the devices and for the device manufacturers along with lot-to-lot controls for the devices. Though a formal evaluation has not been done, DragonWave has demonstrated many of the elements of Quality Level II, and has stated its intent to comply with this level. As a result, Quality Level II will be used for all components in the predictions.

Environmental Factor

Split (IDU-ODU)

The IDU Modem installation is used indoor (IDU) and an environment defined by Telcordia as "Ground, Fixed, Controlled". Telcordia describes this environment as,

> "Nearly zero environmental stress - typical of Central Office or environmentally controlled shelters, vaults, or customer premise areas."

This implies an Environmental Factor of 1.0 as a multiplier for the failure rates of IDU Products. An Environmental Factor of 2.0 as a multiplier for the failure rates of the ODU Products. Further detail on other Telcordia defined environments can be found in Section 9.4.

Outdoor (ODU)

The prediction assumes an environment defined by Telcordia as "Ground, Fixed, Uncontrolled," as would be typical of a DragonWave ODU product installation. Telcordia describes this environment as,

> "Some environmental stress with limited maintenance. Typical applications are manholes, poles, remote terminals, customer premise areas subject to shock, vibration, temperature, or atmospheric variations."

This implies an Environmental Factor of 2.0 as a multiplier for the failure rates of ODU Products. Further detail on other Telcordia defined environments can be found in Section 9.4.

Operating Temperature & Temperature Stress

The prediction was performed and tabulated for a variety of ambient temperatures in accordance with an operating environment as specified in the ETSI standard, ETS 300 019-1-4. An average failure rate is also supplied based on typical varying temperature conditions.

The ETSI standard also requires operation at a low air pressure corresponding to an altitude of approximately 3000 m. At this lower pressure, the lower density of the air results in reduced cooling efficiency. This is particularly significant for long surfaces (1 m or more) and for those which use forced-air cooling. Fortunately, neither of these situations applies to any configurations. Further, air temperature is typically lower at higher altitudes – roughly on the order of 2 °C per 300 m. This reduction in temperature offsets the reduced cooling efficiency due to the lower air density. As a result, the effects of altitude are considered negligible for the current analysis.

For individual components, higher power components usually operate at higher temperatures. In these cases, the prediction for the corresponding components in the assembly should be adjusted accordingly to reflect the higher failure rate. Correspondingly, any components operating at a lower temperature will have a lower failure rate. Depending on the components, variations of between 5 and 10 °C can readily be ignored.

Operating temperatures for DragonWave product configurations were analyzed in cooperation with the DragonWave design and mechanical teams. The information available consisted of both thermal simulation results and actual measured data.

Electrical Stress

Electrical Stress applies to components such as resistors, capacitors, diodes, inductors, transistors, switches, and any component which has a voltage or current rating for which the applied load can vary widely. Higher or lower electrical stress levels would increase or decrease the failure rates accordingly. At no time should the stress levels exceed 90% of the maximum rating (see next section.)

DragonWave typically operates passive components at 50% or less of their electrical ratings. This is consistent with the nominal Telcordia assumption and is used for components where stress was not determined through measurement or calculation.

Capacitors are readily analyzed for their voltage stress level, and tantalum capacitors are particularly sensitive to electrical stress. On this basis, most tantalum and aluminum electrolytic capacitors were analyzed for electrical stress. The results were applied to the analysis and can be found in the prediction spreadsheet.

Thermal and Electrical Over-stress

The prediction assumes that all components are operating within their specifications. There should be prior design analysis to ensure no components are overstressed through the entire range of operation and storage. This is a critical assumption since, traditionally, most field failures are due to over-stressed or miss-applied components, or manufacturing quality problems.

Integrated Circuit Complexity

The failure rate of integrated circuits is partially dependent on the number of gates, transistors, or memory bits in the devices. The SR-332 prediction methodology reflects this

fact. Unfortunately, aside from memory devices, these numbers are not typically stated in component data sheets. Since failure rates do not change rapidly with gate/transistor count, estimates of these numbers can be used. Gate and transistor counts for this prediction have been estimated based on the available information in the data sheets, such as block diagrams, and on similar components. The assumed gate/transistor/bit counts are documented in the prediction spreadsheet.

MMIC Reliability

Some IDU-ODU products incorporates a number of MMIC (Monolithic Microwave Integrated Circuits.) MMIC devices are not addressed by the reliability prediction standard being used - Telcordia, SR-332. Failure rates models for MMIC devices are provided in the 1992, Issue 2 notice for MIL-STD-217f, but they are not necessarily representative of current MMIC technology and would likely yield unrealistically high failure rates. For this reason, MMIC failure rate information has been derived from a number of sources.
“GaAs MMIC Reliability Assurance Guidelines for Space Applications,” found at the Jet Propulsion Laboratories’ Electronic Parts Engineering web-site –
http://parts.jpl.nasa.gov/mmic/contents.htm

Key to reliability prediction for MMIC devices is having test data available for reliability modeling and having an understanding of the activation energies for the failure mechanisms. Activation energies for the primary failure mechanisms of GaAs MMIC devices are typically from 1.2 to 1.8 eV, indicating a high dependency on temperature. Additional failure mechanisms such as ohmic-contact degradation and hydrogen poisoning, with activation energies in the 0.4 to 0.5 eV range, must also be considered.

Prediction Results

The tables provided in Telcordia, SR-332 list compensating factors for local ambient component temperatures down to 30 °C. This reflects the typical low end of operating temperatures for the products that furnished field data for the standard. The formulas provided do allow the calculation of failure rates for lower temperatures, but have not necessarily been verified in the lower ranges. The formulas are based on the activation energy for the dominant failure mechanism for a component, and so are dependent on that mechanism remaining dominant at the lower temperatures.

Steady-State Failure Rate Predictions

Based on the analysis, the failure rate and corresponding MTBF for a number of steady state outside ambient temperatures is given in the following table. The temperatures are in 5 °C increments encompassing the temperature extremes provided by ETSI standard, ETS 300-019-104, February 1992 (ETSI amendment, ETS 300 -19-1-4-A1, June 1997 does not affect these values). For IDU products an indoor ambient temperature of 23 °C is used in the following tables. Note that the failure rates at the extremes of the range are of little interest in

isolation since they do not represent a long-term steady-state condition. They can, however, be used in combination with other values to determine the long-term failure rate.
For more information on Global outdoor average temperatures visit http://plasma.nationalgeographic.com/mapmachine as a reference.

Conclusions

It should be noted that a failure rate prediction is just that – a prediction. It is most useful for comparative purposes such as evaluating the effect of a change in design or for estimating the performance of a new product based on previous products using similar technologies. The actual failure rate is dependent on the performance of individual designers, the quality of the manufacturing process, the product shipping environment and the actual customer application environment. The best absolute values for failure rate are determined from field performance.

The most significant variables in the analysis are the MMIC failure rates and the electrical stress levels. These and other considerations are outlined in the following paragraphs. The overall analysis was conservative and further detailed analysis and testing would likely reduce the total predicted failure rate.

MMIC technology is not as mature as other component technologies and is not addressed directly by the Telcordia standard. As such, conservative values were used based on manufacturers' data calculated using a 60% upper confidence limit. The 60% upper confidence limit implies that, based on the testing performed, the actual performance will be better than the prediction 60% of the time. Often, the testing performed results in zero component failures. Longer term testing by the manufacturers usually results in better, and lower, failure rate predictions for the components. Updated information should be periodically requested from the suppliers and any such updated information can be used to update the analysis.

The failure rate of many components, particularly GaAs MMIC devices, have a strong temperature dependency. Laboratory measurement of case temperatures should be performed for all MMIC devices and any high-power components.

The failure rate prediction results provided are based on specific temperature conditions. For customer applications with ambient conditions differing significantly from those used in the analysis, a custom analysis could be performed based on the relevant (customer-supplied) ambient temperature profile data.

Given appropriate environmental data failure rates for other areas can be calculated similarly.

Painting the ODU's will have a negative impact on MTBF, which are not calculated in the MTBF numbers as there are too many uncontrolled variables to consider. These variables include paint thickness, paint wear, age, distribution, paint type and color. For painted ODU's, DW cannot guarantee the radio or link performance will meet published MTBF.

The baseline reliability numbers were evaluated based on experimental data for a naturally convection cooled radio a still air environment as industry accepted practice.
This environment is used to provide a test baseline which is independent of thermal chamber variability (for example the chamber size and airflow speed). Although this is useful in assessing equipment's suitability under worst case operating conditions it also represents an

overly conservative assessment when related to reliability in a fielded condition. An accurate reliability prediction for outdoor electronic equipment depends on realistic characterizations of ambient operating conditions. In the instances of fielded equipment the reliability predictions are supplemented by field reliability data to more accurately reflect the robustness of the items. For new products this field data is not be available. To provide a bridge between field supplemented reliability numbers and to obtain realistic experimental predicted data, DWI has conducted additional thermal tests on new products in thermal chambers with airflow between 1.8 to 2.8 MPH. The chamber test data will show expected trends for individual radios but should not be used as a qualitative comparison between radio types due to the variations in chamber characteristics (airspeed, flow characteristics etc.).

Version	By	Date	Comments
1.0	Billy Wilson, MGSC	March 8, 2012	Initial release