



SURFACE VEHICLE INFORMATION REPORT

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Product Development Process and Checklist for Vehicle Electronic Systems

RATIONALE

Update references, correct reference numbers in main text, minor technical changes throughout document.

FOREWARD

The traditional approach to electronic system product development and validation is inherently not capable of finding many contemporary issues. The degree of analysis, modeling, simulation, testing, and experience of the design/test staff varies widely among different OEMs and vendors. Another major part of product development is validation in a number of areas, such as functionality, electromagnetic compatibility (EMC), and environmental testing. Although much time and expense is spent, using traditional approaches often leads to “feel good” results since the product “passes.” Such a false sense of security is misleading, since such validation methods can have serious deficiencies. These deficiencies may prevent detection of the types of concerns that exist in today’s automotive electronic products.

Many specs were written when automotive electronics was not mature (lots of issues). Environmental and EMC specs evolved over many years (lots of baggage, old practices). These test methods have many limitations and compromises not appreciated by contemporary practitioners—simple pass-fail criteria can result in non-value work (test issues that are not real-world concerns).

System pareto analysis—top three root causes of field issues (mature OEM, vendor); see Figure 1.

1. Requirements not correct or unspecified (“unrequirements”)
2. System-interface issues
3. Trouble not indicated (TNI)

Many processes focus on D & E instead of top three. Environmental specs are wear-out mechanism oriented—focused on component, solder joint, and mechanical reliability. Major advances in component reliability, design-process maturity, and solder capability have placed these down on pareto list.

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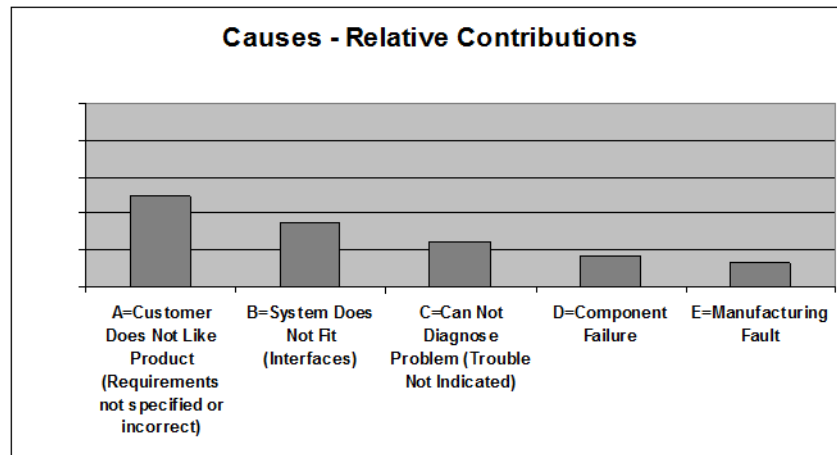


Figure 1 - Relative contributions

To provide information on a robust design process, a handbook for robustness validation (SAE J1211) was published. It was developed by approximately 40 experts in the field (European and American).

It can be summarized by this quote from the SAE J1211 handbook:

“Robustness validation relies first on knowledge-based modeling simulation and analysis methods to develop a highly capable design prior to building and testing physical parts; and then on test-to-failure (or acceptable degradation) and failure/defect susceptibility testing to confirm or identify robustness margins, to enable failure prediction and verify that manufacturing processes produce defect free parts. These techniques represent advancement beyond ‘test-to-pass’ qualification plans which usually provide very little useful engineering information about failure modes, failure mechanisms, and failure points.”

(From SAE J1211)

To obtain a high degree of quality and reliability, a wide variety of subjects needs to be addressed when designing a vehicle electronic system. No single designer can be expected to have the experience necessary to consider all aspects of a design. Such experience is often spread throughout an organization and not concentrated on any one project. This report is meant to condense information from a number of sources to improve the quality and reliability of automotive electronics.

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1. SCOPE

Since it is impossible to be all inclusive and cover every aspect of the design/validation process, this document can be used as a basis for preparation of a more comprehensive and detailed plan that reflects the accumulated “lessons learned” at a particular company. The following areas are addressed in this document:

1. Contemporary perspective including common validation issues and flaws.
2. A Robustness validation (RV) process based on SAE J1211 handbook and SAE J2628.
3. Design checklists to aid in such a RV process.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J551	Performance Levels and Methods of Measurement of Electromagnetic Radiation from Vehicles and Devices (30 to 1000 MHz)
SAE J1113	Electromagnetic Susceptibility Measurement Procedures for Vehicle Components (Except Aircraft)
SAE J1211	Handbook for Robustness Validation of Automotive Electrical/Electronic Modules
SAE J1455	Recommended Environmental Practices for Electronic Equipment Design in Heavy-Duty Vehicle Applications
SAE J1879	Handbook for Robustness Validation of Semiconductor Devices in Automotive Applications
SAE J2628	Characterization, Conducted Immunity

2.1.2 Military Specifications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-810	Environmental Test Methods and Engineering Guidelines
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 7637	Electrical Disturbance by Conduction and Coupling
ISO 10605	Test Methods for Electrical Disturbances from Electrostatic Discharges
ISO 11451	Vehicle Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy
ISO 11452	Electrical Disturbances by Narrowband Radiated Electromagnetic Energy, Component Test Methods
ISO 16750	Environmental Conditions and Testing for Electrical and Electronic Equipment

2.2.2 CISPR Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

CISPR 25	Vehicles, Boats and Internal Combustion Engines, Radio Disturbance Characteristics, Limits and Methods of Measurement for the Protection of On-Board Receivers
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2.3 Other Standards

JEDEC (Joint Electron Device Engineering Council) standards on electronic components, consumer electronics, electronic information, telecommunications, and internet security.

JEDEC JEP 122H, Failure Mechanisms and Models for Semiconductor Devices.

AEC (Automotive Electronics Council) Q100 (Failure Mechanism Based Stress Test Qualification for Integrated Circuits), Q101 (Failure Mechanism Based Stress Test Qualification for Discrete Semiconductors in Automotive Applications), Q200 (Stress Test Qualification for passive Components), and other standards.

2.4 Technical Papers

1. Gaonkar, A., Patil, R.B., Kyeong, S., Das, D., and Pecht, M.G. "An Assessment of Validity of the Bathtub Model Hazard Rate Trends in Electronics."
2. Caruso, H. and Dasgupta, A. "A Fundamental Overview of Accelerated Testing Analytical Models," University of Maryland CALCE Center, College Park, MD, 1998 Proceedings Annual Reliability and Maintainability Symposium.
3. Keimasi, M., Azarian, M.H., and Pecht, M. "Comparison of Flex Cracking of Multilayer Ceramic Capacitors Assembled with Lead-Free and Eutectic Tin-Lead Solders."
4. Rostamzadeh, C., Dadgostar, H., and Canavero, F. "Electrostatic Discharge Analysis of Multi-Layer Ceramic Capacitors," 2009 IEEE EMC Symposium.
5. IEEE EMC Symposium 2005, "Comparison of ISO 7637 Transient Waveforms to Real World Automotive Transient Phenomena."
6. Thienel, C. and Bosch, R. SAE 2009-01-0294, "Avoiding Electrical Overstress for Automotive Semiconductors by New Connecting Concepts," Germany.
7. Fortunato, M. "Temperature and Voltage Variation of Ceramic Capacitors, or Why Your 4.7µF Capacitor Becomes a 0.33 µF Capacitor," Tutorial 5527.

2.5 Books, Handbooks

1. Walker, The Design Analysis Handbook, ISBN 0-9641527-0-3. Provides a practical framework for integrating quality into the design process from start to finish. The methodology used is called worst-case analysis plus (WCA+), a design-validation tool that demands thoroughness and analytical thinking by the user. A guide to assessing and validating circuit design. Presents processes and mathematical tools in a straightforward, real-world manner. Unique features of the approach include chapters on safety, bad science, and surviving high-pressure design projects.
2. Reinertsen, Managing the Design Factory, ISBN 0-684-83991-1. A methodical approach to consistently hit the “sweet spot” of quality, cost, and time in developing any product. Challenges many of the conventional approaches to product development—e.g., test failures are good (maximizes information), design reviews should not be done by part of team (independent evaluation by experts), etc. Full of practical techniques, concrete examples, and solid general principles, this is a real toolkit for product developers. Challenges the thinking of anyone involved in product development.
3. O'Connor and Kleyner, Practical Reliability Engineering, Ed 5, Wiley. With emphasis on practical aspects of engineering, this book has gained worldwide recognition through progressive editions as the essential reliability textbook. The fifth edition retains the unique balanced mixture of reliability theory and applications, thoroughly updated with the latest industry best practices.
4. Horowitz and Winfield, The Art of Electronics, ISBN 0-521-37095-7. Widely accepted as the authoritative text and reference on electronic circuit design, both analog and digital, this book revolutionized the teaching of electronics by emphasizing the methods actually used by circuit designers—a combination of some basic laws, rules of thumb, and a large bag of tricks. The result is a largely nonmathematical treatment that encourages circuit intuition, brainstorming, and simplified calculations of circuit values and performance.
5. Ott, Electromagnetic Compatibility Engineering, ISBN 978-0-470-18930-6. Completely revised, expanded, and updated version of Henry Ott's popular book “Noise Reduction Techniques in Electronic Systems.” While maintaining and updating the core information such as cabling, grounding, filtering, shielding, digital circuit grounding and layout, and ESD that made the previous book such a wide success, this new book includes additional topics. Throughout the book, an emphasis is placed on cost-effective EMC designs, with the amount and complexity of mathematics kept to the strictest minimum.
6. Johnson and Graham, High Speed Digital Design, ISBN 0-13-395724-1. Focused on the field of knowledge lying between digital and analog circuit theory. The scope of the material covered includes signal reflection, crosstalk, and noise problems which occur in high-speed digital machines (above 10 MHz).

3. CONTEMPORARY DESIGN/VALIDATION PERSPECTIVE

Before developing a checklist, it is instructive to be aware of the limitations and history of automotive electronics validation to gain insight into why things are presently done in a certain manner. Such awareness is useful in the design process for a number of reasons including insight for making “hold or fold” decisions.

1. The traditional approach to product validation is to treat the different disciplines required separately. Such an approach often misses issues that cross discipline lines.
2. Market leaders know just “meeting spec” does not necessarily result in a quality product—main goal is to satisfy the end customer and minimize field issues not just pass specs.
3. Component reliability and design practices have greatly improved over the early days of automotive electronics. Consequently, most electronic module issues are functionality, new design (including software), and workmanship-related.

3.1 Test-Related Issues

1. Originally, reliability for automotive electronics was poor so a lot of tests were “invented.” There were minimal design practices for automotive EMC.
2. As product complexity and technology grow, the traditional “cookbook” approach is not effective at finding many real-world concerns.
3. Testing methods have many limitations and compromises not appreciated by contemporary practitioners—don’t know when to “hold or fold.”
4. Much testing addresses old issues with limited value add especially for modules that follow known basic design rules and are mature.
5. Different people looking at the same data can come up with quite different conclusions depending on their background, insight and flexibility.
6. Testing of representative modules often late in design cycle—need more simple development testing to identify issues early.
7. OEM test process is so complex, long, and expensive that it diverts from “play” time to identify bugs early.
8. Simple pass-fail criteria (e.g., limit line) results in too much non-value work (not real-world issues).
9. Test spec plans mainly “test for success”—cannot maximize information by maximizing success rate. Must have failures to maximize information.
10. Typical testing has major purpose of repeatability, not necessarily what is required to find real-world issues (some tests require randomness).
11. Requirements validation (hardware-software) under ideal-pristine conditions. Does not sufficiently address system interactions, robustness. Many tests are idealized simulations of the real world.
12. There is such a large test infrastructure (equipment manufacturers, test labs, large OEM/vendor departments) that it is extremely difficult to change present test methods and limits.
13. With a more focused plan (major emphasis on the analysis and development stages), overall test time and facilities can be reduced (>50% possible) while being more effective and thorough.

*“Testing alone is not sufficient for Design Verification ... Analysis compliments a test program by identifying problems that even the most rigorous testing can miss.”
(From the Design Analysis Handbook)*

3.2 Test Effectiveness Example

It is instructive to give an actual example of typical test method effectiveness. A study of 260 environmental testing anomalies over a 5 year timespan for a major OEM supplier resulted in only three issues identified that would impact the field. Most issues: test setup, unrepresentative module, limit incorrect, known concern before test, minor risk (would not result in field issue).

In a similar manner, field action case histories (not test issues) show that majority are functionality, design, and workmanship issues.

3.3 Cost Reduction (CR)

CRs are a necessary part of doing business but can be very expensive in the long run if not properly managed.

1. Overall cost save can be less than “booked” (engineering time-cost, warranty, field actions, customer satisfaction). One big recall can wipe out years of CR.
2. Diverts resources from original product. CR commonly >50% of engineering resources.
3. Validation limited—often cookbook DV, test for success.
4. Best OEMs slowly introduce or phase-in radical new technology.

3.4 Trouble Not Indicated (TNI)

TNIs are typically very high and can run over 50% (sometimes >80%). One reason TNIs can be high is due to troubleshooting techniques at the dealer where part swapping may occur (once part taken from parts department, can't be returned).

Another reason they are so high is that field returns often use standard tests (e.g., environmental test such as thermal cycle) to try and identify the root cause. It is rare for these tests to identify root cause for reasons identified in 3.1. In addition, the resources and time to find root cause are commonly not available. Often the root cause is a system issue which can be very difficult to investigate and requires expertise that crosses discipline boundaries. As a result, a field return is often identified as TNI.

3.5 Sample Sizes

The preface in SAE J1211 puts sample size in perspective. By the mid-80s, a test sample size of six to 24 units with zero failures is specified (90 to 95% reliability, confidence = 70 to 90%) which is about five to 20 failures/10⁶ hours—not so good by today's standards. Today, reliability is in ppm, which translates to 0.05 failures/10⁶ hours range (test to pass). Reliability demonstration over 99.9% would require thousands of units. It's evident that a smarter approach is required. Sample size, in most instances, does not need to be large for a number of reasons:

1. Most issues are functionality- and design-related, so product responses are similar and can be found with fewer samples.
2. Large sample sizes divert attention from product evaluation (e.g., test complexity).
3. Use of focused testing (weaknesses via up-front analysis—tail testing) and measuring degradation (not just failures).
4. Allows increased monitoring, fewer facilities, and less chamber loading (allows more focusing on product and not on test complexity “red herring” issues).
5. Combining stresses (e.g., thermal, electrical) also reduces sample size requirements.
6. Variables data (e.g., measuring degradation during test) requires fewer samples.
7. Use surrogate data from similar products to reduce number of tests.

3.6 Reliability Prediction

1. Electronics reliability predictions based on models can be non-value exercise if not used responsibly (e.g., no impact on design; just looking for a number).
2. From many years of automotive field experience, real issues would not be predicted from these prediction models.

3. Use of empirical models like MIL-STD-217 by automotive industry is limited. Typical Dept of Defense (DoD) use of MIL-STD-217F notice 2 and 217 plus is limited to support logistics and analysis of alternate designs early in acquisition when empirical data on similar systems or from surrogate data sources are not available. The DoD also uses such methods as physics of failure, FMEA, reliability growth, and reliability demonstration testing.
4. Life testing has limited capability since performed under conditions that often do not reflect the complexity of environmental stresses under end user operational conditions. The typical life test is done by making standard environmental tests longer (e.g., temperature cycling) and does not reflect the aforementioned complexity.
5. Only certain devices typically wear out or degrade—e.g., CD mechanism or vacuum fluorescent display (VFD).
6. Since most electronics will not wear out in useful life of vehicle, should use degree of degradation as basis for life testing (e.g., idle current change, VFD brightness, change in design margins).
7. Robustness validation process (Section 4) more appropriate for 10 year/150k useful life estimation.
8. Validity of the bathtub model for hazard rates is questionable (see 2.4.1).
9. Using accelerating environmental testing has many limitations (see 2.4.2). Based on idealistic equations with many assumptions.
 - a. Uses: Material trade-off studies, comparisons of thermal and structural design alternatives, order-of magnitude estimates of product wear-out rates, evaluations of potential effects of possible design changes.
 - b. Risky uses: Exact predictions of product life, precise contractual life requirements and warranty commitments, generic assumptions for different products, applying cyclic and steady-state models for transient load damage conditions

*"It's much more important to have a reliable product than it is to claim to have a reliable product; i.e., the electronics reliability prediction paradigm is obsolete. Electronic product failures will be primarily due to process, workmanship and design problems."
(From the Design Analysis Handbook)*

4. ROBUSTNESS VALIDATION (RV) PROCESS

There are many sources of information relating to electronics reliability and robustness. Some good examples are listed in 2.5.1 to 2.5.3. However, this section focuses on the SAE J1211 handbook. This recently published document addresses the robustness validation (RV) process that is gaining support (mostly in Europe at this time).

Much of this information can be obtained at <http://www.zvei.org/RobustnessValidation>. As one can see from the following list of major sections, it is quite comprehensive.

1. Information and communication flow.
2. Mission profile.
3. Knowledge matrix.
4. Analysis, modeling and simulation.
5. Intelligent testing.
6. Manufacturing process robustness and its evaluation.
7. Robustness indicator factor.
8. Appendices A, B, C.

A similar document, SAE J1879, was also issued which addresses the RV process at the semiconductor level.