IEC TR 61191-9

Edition 1.0 2023-06

TECHNICAL REPORT

colour
inside

Printed board assemblies –
Part 9: Electrochemical reliability and ionic contamination on printed circuit board assemblies for use in automotive applications – Best practices

IEC TR 61191-9:2023-06(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.180; 31.190 ISBN 978-2-8322-7028-8

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC TR 61191-9 has been prepared by IEC technical committee 91: Electronics assembly technology. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
91/1811/DTR	91/1825A/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61191 series, published under the general title *Printed board assemblies*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The document applies to electronic and electromechanical automotive circuit board assemblies. It describes current best practices for dealing with electrochemical reactions like migration or corrosion and ionic contamination on the surface of a printed circuit board as one failure mode under humidity load.

This document is an informative document which serves to illustrate the technically feasible options and provide a basis for customer and supplier agreements. It is not intended to be regarded as a specification or standard.

Related standards are gathered in the Bibliography.

PRINTED BOARD ASSEMBLIES –

Part 9: Electrochemical reliability and ionic contamination on printed circuit board assemblies for use in automotive applications – Best practices

1 Scope

This part of IEC 61191, which is a Technical Report, applies to electronic and electromechanical automotive circuit board assemblies and describes current best practices for dealing with electrochemical reactions like migration or corrosion and ionic contamination on the surface of a circuit board as one failure mode under humidity load. This document deals with the evaluation of materials and manufacturing processes for the manufacturing of electronic assemblies with focus on their reliability under humidity loads. The electrical operation of a device in a humid environment can trigger electrochemical reactions that can lead to short circuits and malfunctions on the assembly. In this context, a large number of terms and methods are mentioned, such as CAF (conductive anodic filament), anodic migration phenomena, dendrite growth, cathodic migration, ROSE (resistivity of solvent extract), ionic contamination, SIR (surface insulation resistance), impedance spectroscopy, etc., which are used and interpreted differently. The aim of the document is to achieve a uniform use of language and to list the possibilities and limitations of common measurement methods. The focus of the document is on the error pattern of electrochemical migration on the surface of assemblies with cathodic formation of dendrites.

Evaluation of different test methods of control units under high humidity load are not part of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60194-1, *Printed boards design, manufacture and assembly – Vocabulary – Part 1: Common usage in printed board and electronic assembly technologies*

IEC 60194-2, *Printed boards design, manufacture and assembly – Vocabulary – Part 2: Common usage in electronic technologies as well as printed board and electronic assembly technologies*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in IEC 60194-1, IEC 60194-2 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1 Terms and definitions related to management

3.1.1
design authority
individual, organization, company, contractually designated authority, or agency responsible for the design of electrical/electronic hardware, having the authority to define variations or restrictions to the requirements of applicable standards, i.e., the originator/custodian of the applicable design standard and the approved or controlled documentation

3.1.2
manufacturer
individual, organization, or company responsible for the assembly process and verification operations

3.1.3
production part approval process
PPAP
procedure in accordance to IATF 16949 [1] to regulate the sample submission process within the supply chain, primarily used for the series release of new parts

Note 1 to entry: The main objective of the procedure is the regulated start-up assurance with regard to quality and quantity of mass production.

3.1.4
user
individual, organization, company, or agency responsible for the procurement of electrical/electronic hardware and having the authority to define any variation or restrictions to requirements

EXAMPLE Originator/custodian of the contract detailing the requirements.

3.2 Technical terms and definitions

3.2.1
conductive anodic filament
CAF
migration which occurs along the monofilament of reinforcing material such as glass cloth in an inner layer part of a printed wiring board

3.2.2
no-clean
produced with a no-clean solder material and optimized process parameters throughout the entire process chain (e.g. design, printing, soldering), for which flux residues are usually not critical and removal of these residues is not necessary

Note 1 to entry: There could be additional requirements of customers.

3.2.3
resistivity of solvent extract
ROSE
analytical method to determine the integral contamination load on a CB or CBA causing electrical conductivity

3.2.4
surface insulation resistance
SIR
electrical resistance of an insulating material between a pair of contacts, conductors or grounding devices in various combinations, which is determined under specified environmental and electrical conditions

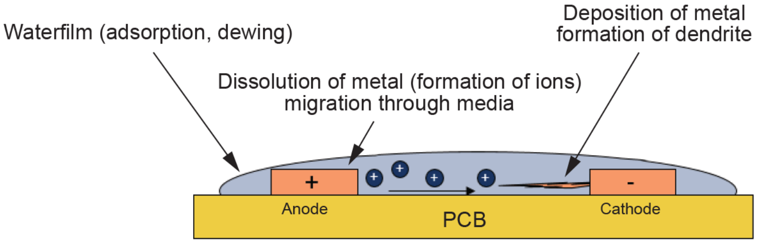
3.3 Abbreviated terms

AIT	assembly and interconnect technology
AMP	anodic migration phenomena
CB	circuit board
CBA	circuit board assembly
DI-water	deionized water
ECM	electrochemical migration
ECU	electronic control unit (CBA with housing)
IC	ion chromatography
ICont	ionic contamination
iSn	immersion tin
OSP	organic surface protection
PB	printed circuit board (bare board as delivered by PB manufacturer) Note 1 to entry: This abbreviated term is not preferred.
PBA	printed circuit board assembly (unit without housing) Note 1 to entry: This abbreviated term is not preferred.
PCB	printed circuit board (bare board as delivered by CB manufacturer) Note 1 to entry: This abbreviated term is not preferred.
PCBA	printed circuit board assembly (populated CB without housing) Note 1 to entry: This abbreviated term is not preferred.
SMD	surface mounted devices
SMT	surface mounting technology
THR	through hole reflow
THT	through hole technology
WOA	weak organic acid

4 Failure mode electrochemical migration

4.1 Background of electrochemical migration

The electrochemical migration on electronic assemblies is understood as the migration of metallic ions such as Ag, Cu, Sn, Ni in a water film on the assembly. The ions are released at the anode (the positive pole of the assembly, e.g. terminal 30), migrate by a diffusion controlled mechanism in the water film to the cathode (the negative pole, e.g. ground, GND) and are deposited there again by reduction with dendrite formation (electrocrystallisation). The dendrite can then grow back towards the anode and create an electrical short circuit. This process can only take place if there is a closed water film between the anode and cathode and if there is a corresponding potential difference. The electrolysis of water always occurs as a reaction, so that a local change in the pH value take place. This can trigger further reactions (e.g. hydrolysis of materials or the formation of poorly soluble metal salts). The processes are shown in Figure 1.



Anode: $6H_2O \rightarrow O_2\uparrow + 4H_3O^+ + 4e^-$ (turns acidic)

$Cu \rightarrow Cu^{2+} + 2e^-$

Cathode: $4H_2O + 4e^- \rightarrow 2H_2\uparrow + 4OH^-$ (turns alkaline)

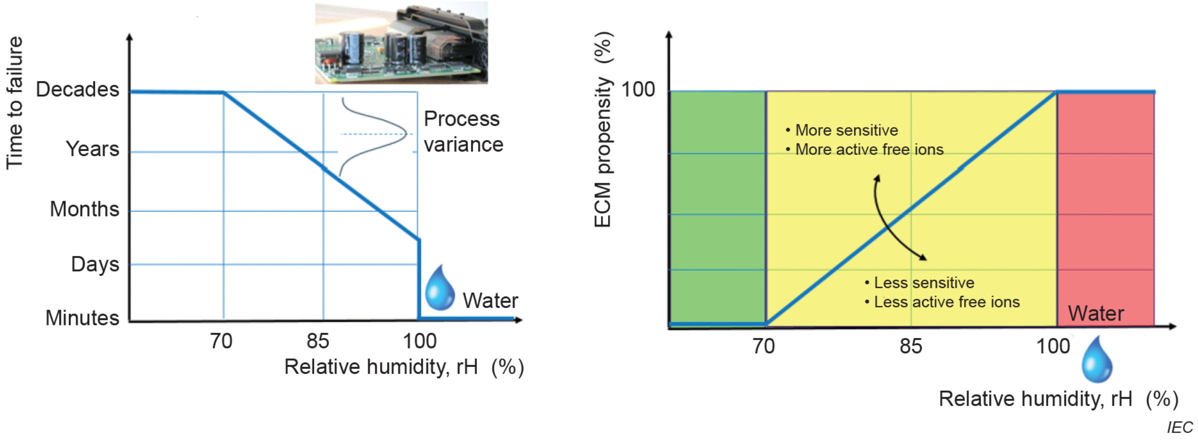
$Cu^{2+} + 2e^- \rightarrow Cu$

IEC

Figure 1 – Principal reaction mechanism of ECM

The process of electrochemical migration itself is fast. Dendrite growth occurs within seconds to a few minutes if a sufficiently thick (> 50 µm) water film (e.g. droplet formation by direct condensation) is formed on the assembly. Thus, electrochemical migration is not an ageing effect of materials, but is triggered by the event of direct condensation. Classical lifetime laws cannot therefore be applied. With very thin closed water films (< 70 % rH with few molecular layers, < 50 nm thickness), this process is significantly slowed down for molecular-structural reasons.

Therefore, ECM is only found if a sufficient amount of water is present locally at a design element having a potential difference (> 1,5 V). It is also visualized that small deviations in material or processing properties can drastically change the criticality of the system concerning ECM. The principal dependencies were presented on [2][1] (Figure 2). It illustrates very well the problem that a failure prognosis based on widely used Peck or Lawson models regarding ECM is not possible due to uncertainty of surface conditions and the fact that dewing events do not follow an ageing law.



See [2].

Figure 2 – Uncertainty in local conditions determines ECM failures

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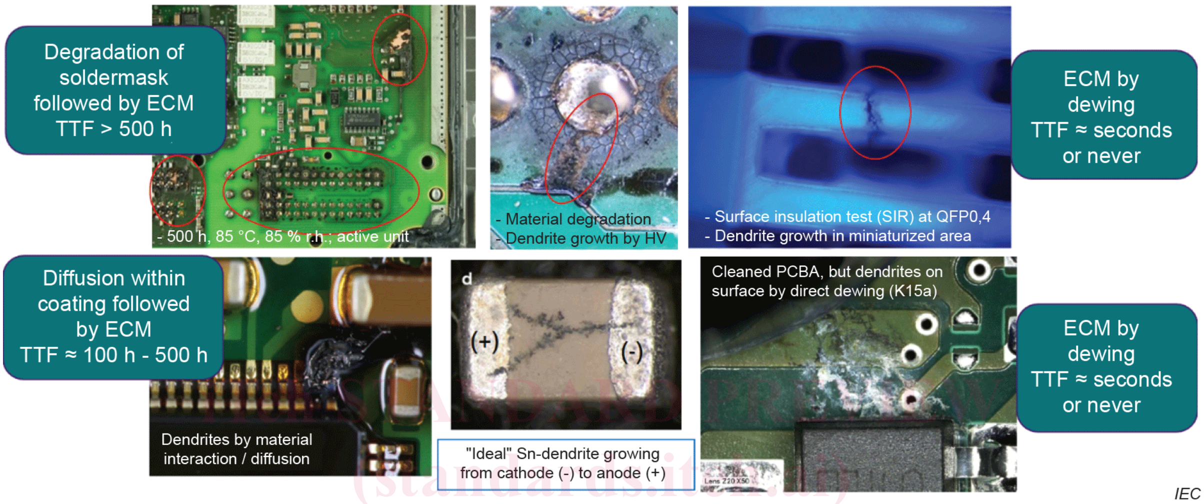
[1] Numbers in square brackets refer to the Bibliography.

The ECM error pattern can also occur with a time delay due to decomposition reactions or diffusion processes. For example, ECM defects below a solder resist or within a conformal coating only occur after sufficient saturation of the materials with water but are significantly delayed by the slow diffusion processes within a polymer. Slow material decompositions (e.g. hydrolysis of polymers by the local change of the pH-value) with an accompanying change of their function (e.g. loss of the insulating effect of a solder resist) also belong to this group. In these cases, ECM will only occur after extended periods of exposure to moisture (weeks to months in high humidity tests). Those findings are illustrated in Figure 3. For degradation or diffusion processes as rate determining step complex, models for failure prognosis could be derived in contrast to the condensation case. However, those models are merely system specific and cannot be transferred to different constructions and materials.



See [3]

NOTE Same failure mode but different reasons.

Figure 3 – Occurrence of ECM failures during humidity tests

In all tests and evaluations of assemblies operated in humid environment, it needs to be minded that humidity can only be accelerated to a limited extent. An acceleration factor cannot be derived in most cases. It needs always to be noted that the failure mechanism is not changed by any test condition or acceleration approaches in a way that will not appear in the intended end-use environment of the product. IEC 60068-3-4:2001 [4] already clearly emphasizes this special feature for electrochemical failure mechanisms where humidity is necessary.

4.2 Complexity of electrochemical migration

The error pattern of electrochemical migration on assemblies is complex. Its occurrence depends on various factors, which are shown in the VENN diagram (Figure 4). The attempt to summarize the complex relationships in a single, easily accessible measured quantity, such as only the reduction of ionic contamination, was therefore incorrect and is a frequent cause of misinterpretations.

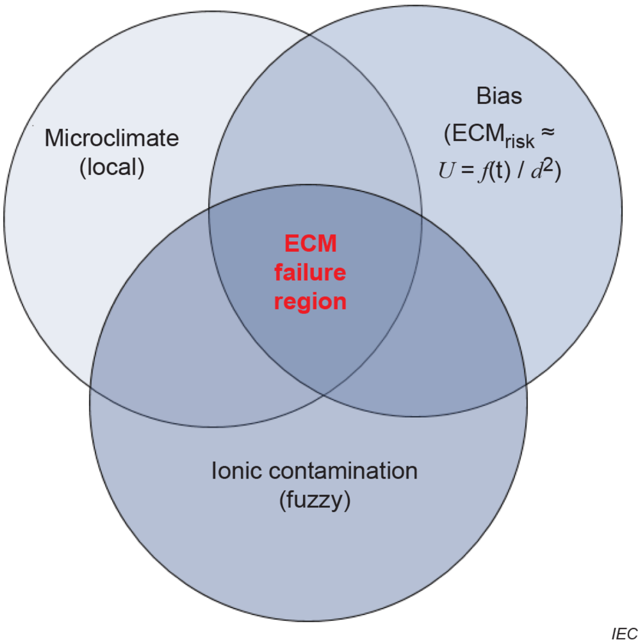


Figure 4 – VENN diagram showing the factors influencing ECM

In order to understand the error pattern of electrochemical migration in its totality, the 3 following main influencing factors need to be analyzed and understood in more detail.

- Bias translated by voltage U and operation time t when U is applied as well as distances d between metals with different potential, where the following relationship applies to the risk of electrochemical migration $P_{ECM} \approx U \times f(t) / d^2$.
- Microclimate translated by local humidity (stress at design element) considering retarded buildup of water path on circuit-board assemblies in a housing, heating-up and dry-out effects, thermal mass of systems.
- Ionic contamination translated by materials properties considering processing, hygroscopic behaviour, degradation of materials, chemical interactions.

For the complex system circuit-board assembly with a multitude of materials and interactions, the measurement of the SIR value in the context of material characterizations as well as active humidity testing of ECUs currently represents the most reliable method for evaluating the electrochemical reliability of an assembly. The measurement of ionic contamination alone does not provide any information about the reliability of an assembly in the intended end-user environment. In 2017, IPC took this into account and eliminated a historical definition with a limit of 1,56 µg/cm^2 NaCl equivalent for cleaned assemblies in IPC-J-STD-001 [5] starting with Amendment 1 to Rev G [6]. A more detailed background is given by the whitepaper IPC-WP-019 [7].

4.3 Conductive anodic filament (CAF) and anodic migration phenomena (AMP)

CAF and AMP belong to degradation mechanisms in CBs that are also triggered by electrochemical processes. In both cases, dendrite-like structures occur, but unlike classical dendrite growth, they propagate from the anode toward the cathode and consist of semiconducting salts. In the CAF failure case, the electrochemical degradation mechanism occurs preferentially along the glass fibre in the epoxy glass fibre composite of a printed circuit board.