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Printed board assemblies –
Part 10: Application and utilization of protective coatings for electronic assemblies

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PRINTED BOARD ASSEMBLIES –

Part 10: Application and utilization of protective coatings for electronic assemblies

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IEC-PAS 61191-10, submitted by GfKORR – Gesellschaft für Korrosionsschutz e.V. was processed by IEC technical committee 91: Electronics assembly technology. It is based on *Guidelines for the application and utilization of protective coatings for electronic assemblies – Selection, fields of application, requirements and application recommendations – provided by the working party “Corrosion protection in electronics and microcircuitry”*. The structure and editorial rules used in this PAS reflect the practice of the organization which submitted it.

The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document
Draft PAS	**Report on voting**
91/1781/DPAS	91/1788/RVDPAS

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G U I D E L I N E S

for the

APPLICATION AND UTILIZATION OF PROTECTIVE COATINGS FOR ELECTRONIC ASSEMBLIES

Selection, fields of application, requirements and application recommendations

Provided by the working party
“Corrosion protection in electronics and microcircuitry”

GfKORR – Gesellschaft für Korrosionsschutz e.V.

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FOREWORD

GfKORR and its working group "Corrosion protection in electronics and microsystems technology" as initiators of this guideline

GfKORR - Gesellschaft für Korrosionsschutz e.V., a non-profit technical-scientific association, which was formed in 1995 from the merger of two predecessor organizations, has set itself the goal of collecting, expanding and disseminating knowledge about corrosion, corrosion mechanisms and corrosion protection possibilities to prevent corrosion damage with the participation of all persons, institutes, companies and facilities involved in corrosion and corrosion protection. This project is to be realized on the one hand through joint conferences, seminars and workshops and on the other hand through constructive work in working groups with special orientation and topics. Further information about GfKORR and its work can be found at http://www.gfkorr.de

The constantly increasing number of different electronic assemblies and miniaturized systems made of various materials and their use, especially in motor vehicles, telecommunications, aircraft, building services and even toys, is also associated with increasing expectations for the functional reliability and long-term stability of the products. In addition, the progressive miniaturization of components places ever greater demands on purity during manufacture and assembly. Furthermore, both electronics and the microcomponents are increasingly exposed to changing climatic conditions such as humidity, temperature changes and temperature shock. Based on long-term warranty requirements and worldwide marketing, an effective assurance of the reliability of electronic products is only conceivable with the help of in-depth knowledge of the mechanisms of action of corrosion of electronic and microsystem components and corresponding corrosion protection measures.

In the spring of 1998, GfKORR founded the working group "Corrosion protection in electronics and microsystems technology" with a view to discussing such ever-increasing issues and problems. It is currently headed by Dr. Helmut Schweigart, Dr. O.K. Wack Chemie GmbH, Ingolstadt; his deputy is Dr. Michael Popall, Fraunhofer Institute for Silicate Research, Würzburg. The working group meets twice a year in Würzburg in spring and autumn (for further information and contact details, see the list of authors and the Internet on the GfKORR homepage).

The working group includes representatives from industry (such as ALTANA Chemie AG, CiS Institut für Mikrosensorik gGmbH, Continental AG, Dage Electronic Europa Vertriebs GmbH, Dow Corning GmbH, GTL Knödel GmbH, Hella KGaA, ISO-ELEKTRA Elektrochemische Fabrik GmbH, KC-Kunststoff-Chemische Produkte GmbH, Lackwerke Peters GmbH & Co. KG, Nordson-Asymtek, Specialty Coating Systems, Stannol GmbH, Wevo-Chemie GmbH, Würth Elektronik GmbH & Co. KG, Zollner Elektronik AG...) as well as employees of various research institutions and service providers (such as the Fraunhofer Institute for Applied Materials Research (IFAM), for Silicate Research (ISC) and for Silicate Technology (ISiT) and the Karlsruhe Research Center GmbH).

The goals of the working group are:

- the deepening of the understanding of the mechanisms leading to functional hazards,
- the interdisciplinary exchange on the state of science and technology in the working fields of the working group in cooperation with industry and other scientific-technical societies,
- damage assessment and prevention, and
- the provision of competent contact persons for acute questions.

An important point that the working group has already dealt with in the past and must continue to deal with is the current test methods for characterizing the protective coatings applied to printed circuit boards and components. Here it is important to make further developments, which, however, can only be pursued jointly by coating manufacturers and users.

The GfKORR working group "Corrosion protection in electronics and microsystems technology" has in recent years focused its work on the compilation of the present guideline and discussed individual points controversially. This guideline, entitled "Application and processing of protective coatings for electronic assemblies - selection criteria, areas of application, requirement profiles and application notes", is based on the knowledge that a comprehensive and fundamental understanding of the coating and its function on electronic assemblies is required. For this, it is necessary to analyze the entire process. This guideline is intended to provide practical assistance in considering this process, starting with the layout up to the functional test of the assembly after the coating.

In order to achieve optimum results in the application of protective coatings, it is also desirable that both manufacturers and assemblers of electronic assemblies and users of protective coatings discuss and implement the desired properties and the necessary and possible process steps together with the manufacturers of protective coatings. Only with such "round-table" discussions can successful solutions be developed for each individual application. It is then also possible to update and improve this guideline at regular intervals through such meetings and discussions.

September 2018
The authors of the guideline

INTRODUCTION

During their production and use in the field, electronic equipment and assemblies are exposed to the influence of moisture and environmental conditions (air, weather, location of the assembly, storage and cleaning) Air, humidity and water lead to an electrical conductive connection of adjacent metal surfaces, which may have different electrical potentials and may thus cause disorder of the electrical insulation by developing additional electrical pathes. Other influences like fluctuations of temperature or strain caused by harmful substances, vibrations and mechancial strain lead to changes in the electrical conduction properties and changes and destruction of the conductor and insulation materials.

Disorder caused by water or moisture often disappears in a dry environment. Also changes of the electrical conductivity caused by temperature disappear when used at modereate ambient temperatures. However, the material, which was destroyed by thermal or mechanical strain, remains in its destroyed condition. A disorder caused by moisture may therefore disappear in favourable cases, however, in view of functional safety considerations of electronic assemblies also such damages must be avoided.

An electronic assembly is only suitable if a safe performance is guaranteed for a specified time. The majority of assemblies is installed in final equipment without any insulation and operate throughout their lifetime without failure. However, the assembly is increasingly used under more difficult conditions. In such cases, safe operation of an assembly is only guaranteed by a protective coating.

Reliability of an electronic product and customer satisfaction are of utmost importance for the success on the market. Product liability requires the manufacturers to take the necessary steps in order to ensure safe operation of electronic equipment also under such heavy conditions. This mainly applies to assemblies which are used in space technology and aviation , defence technology, medicine and automotive industry.

Generally, the coating of the assembly is the last step in the value-added chain of the assembly. Any fault during this step may become very cost intensive and in the worst case may cause disastrous results in the field. Therefore, these guidelines represent a co-operative effort by design engineers, producers, coating engineers and users of electronic equipment. It was decided to establish these guidelines because of the fact that comprehensive and elementary knowledge of the coating and its performance on electronic assemblies is vital. For this purpose, it is necessary to analyse the entire process critically.

These guidelines shall help control in practice the application of protective coatings from the layout to the functional test of the assembly after coating.

Nowadays, coating materials for electronic assemblies are nearly exclusively available in liquid form. The application of powder to certain components as well as full body or partial application of molten foils is limited to exceptional cases. Besides the complete sealing of electronic assemblies, the protective coating offers a cost-effective and user-friendly alternative.

Therefore, the present guidelines especially deal with the requirements for the protective coating, its properties, as well as the application of liquid coating materials. [1].

The German terms „Lacke“ and „Anstrichstoff“ are generally and synonymously used for pigmented and non-pigmented coating materials. The coatings for the protection of electric assemblies described herein are non-pigmented paints. However, a non-pigmented paint should be called clear paint.

In order to stay as neutral as possible, the generic terms coating material and coating process were used herein if further definitions were not expressly required. If more emphasis is placed on the properties of the protective coatings especially described herein, then the term protective paint is used.

In order to set out the scope of these guidelines, the following limitations were made:

- The protective coatings described in these guidelines are protective paints (Conformal Coatings, CC[2,3] or Protective Coatings, PC).
- Protective coatings are polymer layers which protect assemblies against negative influences in service in order to extend their lifetime and operating time, resp.
- If the contours of the assembly are still visible, the polymer coating is defined as protective paint and protective coating resp.- conformal coating -.
- If the contours are entirely covered, then coating resins, casting resins and/or sealing compounds are concerned.
- The entire sealing of an assembly and the processes to be used are not part of these guidelines (see also [Kli05a, Ott05, Ott07 Pie07 HdT07]).

The coating of electronic assemblies is a part of the assembly production developing continuously and quickly. It is therefore planned to update the guidelines on a regular basis and to add more chapters by the GfKORR study group. [4].

[1] According to DIN EN 971-1 (1996-09; „Lacke und Anstrichstoffe – Fachausdrücke und Definitionen für Beschichtungsstoffe – Teil 1: Allgemeine Begriffe“; in the meantime replaced by DIN EN ISO 4618 (2003-12) „Beschichtungsstoffe – Begriffe“) coating material is defined as follows: „Coating material is either a liquid product, or a paste or powder which, when applied to a surface, provides a coating with protective, ornamental and/or other specific properties. “.

Note: The German term „Beschichtungsstoff“ acc. to this specification is the generic term for paints , coatings and similar products. According to the supplement of the DIN EN 971-1 coating materials are also materials for the production of synthetic resins, filler compounds, floor coating compounds, as well as similar materials. The terms coating material, coatings and paint are used alternatively. This also applies to the term „Anstrichmittel“ [Zor98] which is not standardized and should hence be avoided. .

[2] The term “conformal coating” is used in the English and American language and acc. to IPC-CC-830 is defined as follows: “For the purpose of this specification (IPC-CC-830) the term conformal coating is used herein when referring to a type of protective coating for use on printed board assemblies. The conformal coating is intended to provide protection from moisture, contamination and provide electrical insulation; not as a sole source of mechanical support.” The same applies to conformal coatings acc. to UL 746 C („Standard for safety for polymeric materials – use in electrical equipment evaluations“).

[3] The term „conformal coating“ was introduced and used for full body coatings, therefore the term shall be used herein, allthough nowadays “conformal coating” is very often used by mistake in case of one-sided selective coating of electronic assemblies.

[4] The first edition of the guidelines is dated November 2005. This is the second edition dated June 2007, updated and extended for the first time by 30 pages.

REQUIREMENTS FOR THE COATING OF ASSEMBLIES

1 General requirements

2 Climate impact requirements

3 Regulations for protective coating

3.1 Reference to the general requirements

3.2 Reference to climate impact

1 General requirements

Due to the continuous miniaturization of printed circuit boards in recent years, live components and conductors are moving ever closer together, increasing the risk of leakage current formation under moisture. Due to the good dielectric properties of protective coatings, minimum distances between live conductors can be reduced.

In addition, depending on the coating system used, protection against

- mechanical abrasion, vibration and impact,
- atmospheric humidity and hand perspiration,
- chemicals and environmental gases,
- mold infestation in tropical conditions,
- metal splinters/particles.

can be achieved. The surfaces to be coated on assemblies can be of very different types, e.g.

- metal surfaces (tin, tin lead, gold, nickel, copper etc.),
- plastic surfaces (solder resist, PCB base material, component housing, etc.) or
- residues from various soldering processes (HAL = Hot Air Levelling, reflow soldering, solder paste residues, etc.), welding, gluing and other processes.

Very different surface topographies must be taken into account:

- plane surfaces (horizontal, inclined and partly vertical),
- inner edges, outer edges and corners,
- tips and pods,
- wires, curved terminal frames (component connections),
- shadow areas that are not accessible in a straight line, and
- narrow gap (expansion gap).

In general, very high demands are placed on optimum protective coatings, e.g.

- protection against moisture by forming an electrically insulating material barrier,
- avoidance of corrosion phenomena through a coating,
- good adhesion of the coating to the various metal and plastic surfaces,
- simple, cost-effective, fast coating process,
- cost-effective coating material, as little material input as possible,
- complete curing and/or drying under moderate conditions in a short time, even under the components,
- all areas to be protected must be coated;,
- as uniform and homogeneous layer coating thickness as possible at all points,
- reparability should be possible,

- simple visual control of the presence of the coating,
- easy determination of the thickness of the coating at any point.

These requirements can be largely covered with thin-layer protective coatings. In case of additional loads, especially in aggressive industrial atmospheres, high potential differences and other possible loads, thick-film coatings or casting compounds are used to protect the electronics.

Most protective coatings are applied in liquid form and only achieve their specified properties after drying and, depending on the coating material, after chemical curing. This means that a fixed time requirement and corresponding ambient conditions for curing or drying are necessary. The aim is to minimize the time required to coat the assembly and to cure it safely and quickly. Considering the protective coating in terms of cost, application time and environmental impact, the requirements are slightly different, e.g.:

- as solvent-free as possible (solvents have a hazard potential and must be safely removed);
- free of prohibited hazardous substances (e.g. ELV, RoHS Directive[1]),
- drying and curing under normal room conditions if possible (a need for heat etc. increases the coating effort),
- complete drying and/or curing within a short time (long curing times or slower curing with thick layers also increase the effort),
- maximum adhesion and maximum electrical insulation after a short time,
- good robustness of the protective coating during further production and protection of the assembly against the expected loads.

2 Climate impact requirements

The protection of the electrical assemblies against ambient humidity and/or condensation is the most important requirement for the protective coating. This becomes understandable when one considers the use of one and the same assembly under all geographically and climatically possible conditions.

Different climatic stresses - in terms of environmental parameters - under which an electrical assembly must function are:

- low/high humidity,
- low/high temperature,
- different air pressures,
- rapid climate changes,
- condensation,
- microbiological contamination and
- low/high pollution.

The following model illustrates the occurrence of an electrical fault in the presence of wa-

[1] RoHS = Restrictions on Hazardous Substances; Directive published in the Official Journal of the European Union L 214/65 of 18.08.2005

ter or moisture (see Fig. B1). Two closely adjacent metal surfaces have different electrical potentials. In the presence of a connecting water bridge, a current flows due to the potential difference, which can be transported due to the natural conductivity of the water and additionally substances dissolved in the water such as ions and acid components. The disturbance of the function due to electrical lines connected to water depends on the level of the electrical potential difference, the tolerance sensitivity of the electrical quantities, the duration of the presence of water, the conductivity and the cross-section of the aqueous bridge. The current flow over an aqueous bridge can be estimated mathematically if the potential difference is known, the specific conductivity of the water involved, the cross-section of the water connection and the distance between the adjacent metal surfaces.

When the surfaces dry off again, the flow of current through the aqueous compound stops and the interference can disappear again.

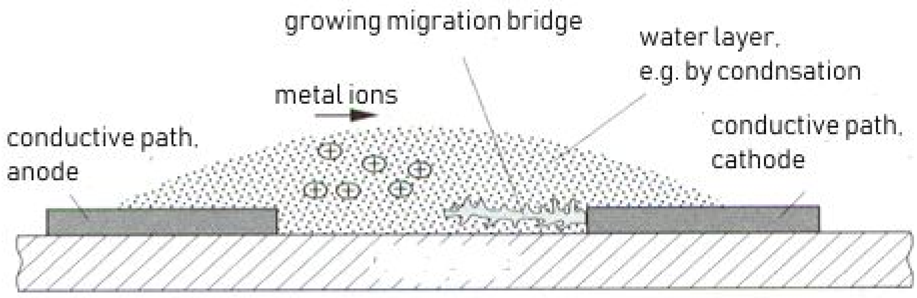

Fig. B1: *Model of the development of a water-related electrical disturbance:*
(a) There is charge transport in the liquid medium water
(b) Metal ion transport to the cathode can cause dendrite growth, i.e. metallic and oxidic material deposits are formed

Possible causes for such influences of water can be:

- Water absorption of materials,
- warm humid air,
- cooling air until condensation (see Fig. B2), rain,
- splash water,
- high pressure cleaning and
- leaking liquids.

In the case of fully assembled structures, the assembly connections, their soldering and their transition into the component are added as additional relevant surfaces, which can have an influence on the behavior under moisture.

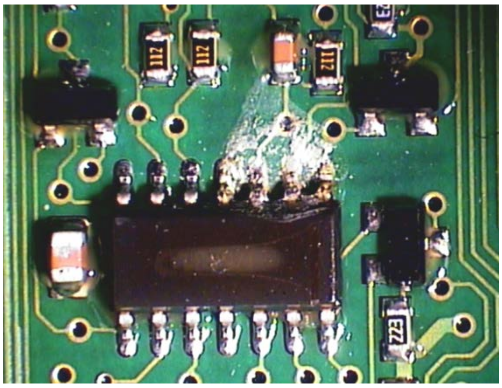

Fig. B2: *Possible fault pattern on an assembly after electrical operation with clear condensation (white-colored area shows a large accumulation of corrosion products)*

Examples of possible malfunctions of electronic control units due to the presence of moisture could be:

- Sensitive signals exceed the tolerance limits; the control unit switches off.
- High-resistance components are bridged by a low-impedance water bridge; the electrical control changes.
- Closely adjacent conductor tracks or connections and high potential differences cause leakage currents in the presence of moisture. This can increase overall power consumption. As long as the power supply is not interrupted or limited by a fuse or electronic control, this can lead to unforeseen heating of the conductors and their insulation.

3 Regulations for protective coating
3.1 Reference to the general requirements

The general requirements for protective coatings are included in many national and international regulations. The following list provides a brief overview of these rules and regulations:

- **IEC 61086-1** *"Coatings for loaded printed wire boards (conformal coatings) – Part 1: Definitions, classification and general requirements"*
- **IEC 61086-2** *"Coatings for loaded printed wire boards (conformal coatings) – Part 2: Methods of test"*
- **IEC 326-3** / IEC 326-3A (1982) / DIN IEC 326 Part 3 (03:1985) *"Printed Circuits, Circuit Boards, Design and Application of Printed Circuit Boards".*
- **IEC 60464-3-1 Ed. 2.0 b** „*Varnishes used for electrical insulation - Part 3: Specifications for individual materials - Sheet 1: Ambient curing finishing varnishes*"
- **DIN 46449 (1970-04)** RETRACTED*"Insulating varnishes and insulating resin compounds in electrical engineering, coating varnishes, test methods".*
- **DIN EN 60664-1 (2008-1)** *DIN EN 60664-1 (2008-1 2003-11) "Insulation coordination for electrical equipment in low-voltage systems - Part 1: Principles, requirements and tests""*
- **DIN EN 60664-3 (2017-11)** *DIN EN 60664-1 (2008-1 2003-11) "Insulation coordination for electrical equipment in low-voltage systems - Part 3: Use of coatings, pouring or encapsulation to protect against contamination"*

- **IPC-CC-830** *"Qualification and Performance, Insulating Compounds for Printing Circuits Assemblies"*
- **IPC-SM-840** *"Qualification and Performance of Permanent Solder Mask – with Amendment 1"*
- **IPC HDBK-830** *"Guidelines for Design, Selection and Application of Conformal Coatings"* [2]
- **IPC-TM-650** *"Test Methods Manual"* (Update service for two years)
- **UL 94** *"Tests for Flammability of Plastic Materials for Parts in Devices and Appliances"*
- **UL 746 C** *"Polymeric Materials – Use in electrical Equipment Evaluations"*
- **UL 746 E** *"Polymeric Materials – Industrial Laminates, Filament, Wound Tubing, Vulcanized Fibre and Materials used in Printed Wiring Boards"*
- **MIL-I-46058** *"Insulating Compound, Electrical"* (for Coated Printed Circuit Assemblies); *has been discontinued and replaced by IPC-CC-830B*

The above standards mainly refer to an evaluation of the coating system. Requirements for the complete assembly and its production process can be found in the specifications of the users, especially from the automotive, aerospace and aerospace industries. The OEM specifications (Original Equipment Manufacturing) mainly describe the requirements for lifetime reliability in the respective end applications.

3.2 Reference to climate impact

The reliable functioning of an assembly under climatic conditions is decisive for the need for a protective coating. For this reason, the following information is limited to the contents of the regulations that describe climatic loads and their requirements.

The climatic resistance can be tested by measuring mechanical, chemical and/or electrical properties. In the regulations, climate resistance is defined mainly by the change in electrical resistances in a test cycle. Among other things, there is a requirement to maintain electrical insulation through the protective coating. Here, for example, the following load parameters and limit values can be found:

IPC-CC-830:

Insulation resistance: **During and after Moisture**

Class A:	100 MOhm
Class B:	500 MOhm

"climatic or test conditions": Alternating test 65°C / 25°C at 90 - 98 % r. H.[3] (defined times and ramps), measured on a defined IPC test plate.
The Class B requirement applies to hydrolytically stable protective coatings and Class A to non-hydrolytically stable protective coatings.

IEC 1086-1 to -3:

Insulation resistance after damp heat: > 1×10^{10} Ohm

"climatic or test conditions": 10 days constant climate 40°C at 93 % r. H., measured on a defined IPC test plate after reconditioning at room temperature.

[2] For the content of the IPC-HDBK-830 and the link to the GfKORR Guide, see Part N of the Guide.

[3] r. H. = Relative humidity

IEC 1086-1 distinguishes between general requirements (Class I) and high reliability (Class II), but makes no difference in this test.

IEC 60464-3-1:

Contact resistance after immersion:
Before: > 10^{12} Ohm x cm
After: > 10^{8} Ohm x cm

Effect of immersion on dielectric strength:
After: > 40 kV/cm

"climatic or test conditions": Constant 23°C water temperature for 7 days (dist. water).

DIN 46449 (withdrawn see DIN EN 60544):

Specific volume resistance as a function of storage in water after 24, 48, 96 and possibly 240 h.

No limit values are specified.

DIN VDE 0110-3 [4]:

Insulation resistance: ≥ 100 MOhm

"climatic or test conditions": 4 days constant climate 40°C at 93 % r. H., measured on a defined IPC test comb.

UL 746 C:

The measured variables are the dielectric strength, at least 50% of the value for the unconditioned sample and at least 1 kV for 60 s.

UL 746 C distinguishes between two conditionings:

- *Environmental Cycling Conditioning*

  This conditioning distinguishes between indoor and outdoor applications:

  - "indoor end-use application": 24 h service temperature, 96 h at 35°C / 90 % r. H., 8 h at 0°C
  - "outdoor end-use application": 24 h water storage at 25°C, 24 h service temperature, 96 h at 35°C / 90 % r. H., 8 h at -35°C

- *Humidity Conditioning*

  "climatic or test conditions": 7 days constant climate 35°C at 90 - 95 % r. H., measured within 2 minutes after removal from the air conditioner on a special UL test plate.

[4] DIN VDE 0110-3 (valid up to 2006-04) = DIN EN 60664-3 (2017-11) "Insulation coordination for electrical equipment in low-voltage systems - Part 3: Use of coatings, pouring or encapsulation to protect against contamination".

Not to forget the IEC series *"Basic Environmental Testing Procedures"*, of which there is a series of around 70 test procedures covering a wide variety of climatic and mechanical stresses.

The presentation of further tests for climate resistance by means of measurements of mechanical, chemical and/or other electrical properties would go beyond the scope at this point. An additional list is therefore not included.