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TECHNICAL SPECIFICATION

colour inside

Basic qualification of DC-link film capacitors for automotive use – General requirements, test conditions and tests

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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BASIC QUALIFICATION OF DC-LINK FILM CAPACITORS FOR AUTOMOTIVE USE – GENERAL REQUIREMENTS, TEST CONDITIONS AND TESTS

FOREWORD

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IEC TS 63337 has been prepared by IEC technical committee 40: Capacitors and resistors for electronic equipment. It is a Technical Specification.

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

Draft	Report on voting
40/3093/DTS	40/3117/RVDTS

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 Specification 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.

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- withdrawn, or
- revised.

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

This Technical Specification is based on a publication of the "ZVEI/ECPE Film Capacitors Core Group" working group with representatives from vehicle, device and capacitor manufacturers. It is adopted to the electrical specifications valid for electrically propelled vehicles – voltage class B systems, as given in ISO 21498-1.

Because AEC-Q200 is not applicable for the capacitors considered here, this document defines a set of tests to ensure the basic suitability of the capacitor for application as a DC-link capacitor in HV applications or in the intermediate circuit of the 48 V on-board electrical system.

This Technical Specification makes no claim to completeness. Automotive manufacturers and device manufacturers are free to request additional state-of-the-art tests at any time. It is also important to understand that a basic qualification as described in this document cannot replace a comprehensive technology qualification being performed in advance of product development.

As the individual manufacturers can make changes, only the company standards of the respective manufacturers created on the basis of this Technical Specification apply.

BASIC QUALIFICATION OF DC-LINK FILM CAPACITORS FOR AUTOMOTIVE USE – GENERAL REQUIREMENTS, TEST CONDITIONS AND TESTS

1 Scope

This document provides requirements, test conditions and tests to validate characteristics including the service life of customized DC-link film capacitors for use in motor vehicle components.

Standard DC-link capacitors qualified according to other IEC standards or AEC-Q200 are excluded from the scope of this document.

The requirements, test conditions and tests listed in this document apply to customized film capacitors developed for use in motor vehicle power electronics for the application as a DC-link capacitor in HV applications or in the intermediate circuit of the 48 V on-board electrical system.

These qualification requirements can be expanded or adapted for the application of technologically innovative designs, if necessary. The content and scope of supplements is therefore to be specified and documented in coordination between the responsible parties prior to sourcing.

Power electronics in the motor vehicle need to be tested in accordance with the environmental qualification standards of the vehicle manufacturers.

The tests in this document do not replace the tests specified in the Component Requirement Specifications for complete vehicle components or additional or deviating further requirements, test conditions and tests described therein.

This document contains no tests to validate the thermal interface between capacitors, power electronics and the cooling system on the component level.

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 60068-1, *Environmental testing – Part 1: General and guidance*

IEC 60068-2-2, *Environmental testing – Part 2-2: Tests – Test B: Dry heat*

IEC 60068-2-14, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

IEC 60068-2-64, *Environmental testing – Part 2-64: Tests – Test Fh: Vibration, broadband random and guidance*

IEC 60068-2-78, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*

IEC 60384-1:2021, *Fixed capacitors for use in electronic equipment – Part 1: Generic specification*

IEC 60695-11-10, *Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods*

IEC 60695-2-12, *Fire hazard testing – Part 2-12: Glowing/hot-wire based test methods – Glow-wire flammability index (GWFI) test method for materials*

IEC 61071:2017, *Capacitors for power electronics*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 21498-1:2021, *Electrically propelled road vehicles – Electrical specifications and tests for voltage class B systems and components – Part 1: Voltage sub-classes and characteristics*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the following terms and definitions 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 General terms and definitions

3.1.1
component
complete device, control unit or mechatronic (with housing)

3.1.2
component element
single part of a component

Note 1 to entry: In this document, "component element" designates a capacitor as described in the Scope.

3.1.3
system
functionally linked components, e.g. power train consisting of electric machine, power electronics, control

3.1.4
device under test
component element to be tested, system or the component to be tested

3.1.5
vehicle pre-conditioning
vehicle climate control prior to departure using energy from the mains supply

3.2 Terms and definitions related to operating voltages and temperatures

3.2.1
working voltage
U_{op}
DC voltage that can occur in an electric system under normal operating conditions according to the customer's specifications, disregarding transients and ripple

Note 1 to entry: The working voltage shall be less than the rated DC voltage.

[SOURCE: ISO 21498-1:2021, 3.16 modified – "AC voltage (rms) or" has been deleted and Note 1 to entry has been added.]

3.2.2
overvoltage
U_{max}
maximum permissible voltage which can be applied to a capacitor for a specified duration at the specified temperature

Note 1 to entry: The maximum permissible voltage specified for a capacitor includes transients, ripple or other disturbances, which can appear within the system under abnormal operating conditions. The duration, number and accumulated duration of overvoltage events need to be agreed between manufacturer and user.

Note 2 to entry: This definition additional to that of the rated DC voltage 3.2.3 is necessary to reflect the customer specifications valid for electrically propelled vehicles (mission profiles), which include normal operation at battery voltage and abnormal operation (overvoltage events), see Annex C for details.

3.2.3
rated DC voltage
U_{RDC}
U_{NDC}
<capacitor> maximum operating voltage of either polarity but of a non-reversing type waveform, for which the capacitor has been designed for continuous operation disregarding transients

Note 1 to entry: The rated DC voltage of the capacitor is aligned with the maximum battery voltage, for which the system is designed. It does not include overvoltage events, like transients. See Annex C for details.

Note 2 to entry: The rated voltage in this specification is different from the general "rated voltage" which is defined in IEC 60384-1 in order to align it to the specification of operating conditions in motor vehicle power electronics.

Note 3 to entry: In IEC 61071 the symbol U_{NDC} is used, but since the letter "N" normally stands for "nominal" it is replaced in this document by "R".

[SOURCE: IEC 61071:2017, 3.18 modified – "maximum operating peak voltage" has been replaced by "maximum operating voltage", "disregarding transients" has been added at the end of the definition, Note 1, Note 2 and Note 3 to entry have been added.]

3.2.4
maximum operating temperature
T_{max}
<capacitor> highest temperature at which the capacitor can be operated under steady state conditions for a specified duration

Note 1 to entry: T_{max} is the temperature of the case measured at the hottest point of the case if no self-heating occurs, or the hotspot temperature inside the case under ripple current load condition. The terminations are part of the external surface of the case.

Note 2 to entry: The temperature time profiles shall be agreed between manufacturer and user.

[SOURCE: IEC 61071:2017, 3.34, modified – "highest temperature of the case" has been replaced by "highest temperature", "for a specified duration" has been added, as well as Note 1 and Note 2 to entry.]

3.2.5
hotspot temperature
the highest temperature present inside the capacitor dielectric

Note 1 to entry: The hot spot temperature cannot be directly measured in operation. Normally the position of a hot spot and the temperature increase by ripple current load is determined by use of simulation tools and verified by measuring the temperature increase at a sample specially prepared with thermal sensors.

[SOURCE: IEC 61071:2017, 3.35, modified – Note 1 to entry has been added.]

3.3 Symbols and abbreviated terms

For the purposes of this document and the subordinate specifications, the following symbols and abbreviated terms apply.

C	capacitance
C_0	initial capacitance on the new part
C_N	nominal capacitance
ΔC	measured change in capacitance after exposure
ΔT	rise or change in temperature in general
ESL	equivalent series inductance
ESR	equivalent series resistance
f	frequency
HV	high voltage
I	current
R_{iso}	insulation resistance
RH	relative humidity
T_{RT}	room temperature
T_{amb}	ambient temperature of a capacitor
T_{max}	maximum operating temperature (3.2.4)
T_{min}	minimum ambient temperature (lower category temperature, typically -40°C)
T_{op}	operating temperature
tanδ	loss factor
U_{op}	operating voltage
U_{RDC}	rated DC voltage <capacitor> (3.2.3)
U_{max}	overvoltage limit, test voltage for high temperature overvoltage test
U_t	test voltage
(dU/dt_{pulse})	set value for charge/discharge test
(dU/dt_{short})	set value for the short-circuit test
U_{TC}	isolation voltage of the terminals (T – Terminal) to the case (C – Case)

4 General requirements

4.1 Deviations from this document

Any deviations from this Technical Specification are listed on the cover sheet of the company standards (in justified exceptional cases, deviations may be represented in the body of the standard in italics). If, in individual cases, modifications to individual test sections are required, such modifications shall be agreed upon separately between the departments responsible of the manufacturer and the user.

4.2 Service life and qualification tests

A vehicle with an electric power train is typically described with the design service life parameters given in Table 1.

Table 1 – Example for a design service life

Service life	15 years
Mileage	300 000 km
Operating hours, driving	8 000 h
Operating hours, charging/ pre-conditioning	30 000 h (22 000 h charging + 8 000 h vehicle pre-conditioning)

The tests described in Clause 5 to Clause 7 are intended to validate the characteristics and service life of capacitors for use in the vehicle.

The basis of the specified tests are the currently-known failure mechanisms and the motor vehicle-specific application profiles of power electronics.

The validation includes:

a) Electrical characterisation (frequency-dependent)
   - E-01 Capacitance;
   - E-02 Insulation resistance;
   - E-03 ESR;
   - E-04 ESL;
   - E-05 Insulation strength to surrounding area (e.g. housing).

b) Mechanical characterisation
   - M-01 Geometry;
   - M-02 Visual inspection.

c) Environmental tests / exposure tests
   - B -01 Thermal shock;
   - B-02 Damp heat, steady state;
   - B-03 High temperature;
   - B-04 Vibration;
   - B-05 Charge/discharge test;
   - B-06 Short-circuit test.

The characterisation measurements are intended to determine the basic functional characteristics and mechanical data of component elements. They shall be performed before, during and after the test.

The environmental tests simulate the exposure of components in the vehicle, and thereby, of the component element.

In addition, applicable safety requirements are described in Clause 9.

In Annex A, an example for data sheet and test report is given.

Annex B lists test to be performed in case of changes to the capacitors.

Annex C provides further explanation of the relation between voltages, temperatures and operating conditions.

4.3 Standard tolerances

Tolerances refer to the set value and the measured value. Ensure that the specified tolerances are complied with independent of the tolerances of the test system. If no other tolerances are specified in the individual tests, use the tolerances from Table 2 or Table 3.

If two tolerance values are specified, the first value listed specifies the upper tolerance and the second value listed specifies the lower tolerance of the value range.

Table 2 – Definitions of standard tolerances for set values

Frequencies	±1 %
Temperatures	±2 °C
Indirectly determined temperatures	±5 °C
Humidity	±5 %
Times	+5 %; –0 %
Voltage	±2 %
Currents	±2 %

Table 3 – Definitions of accuracy for measured values

Insulation resistance	–5 %
Capacitance	±0,5 %
Voltage	±0,5 %
Currents	±0,5 %

4.4 Standard values

Unless otherwise specified, the standard values for measurement in accordance with Table 4 shall apply.

Table 4 – Definitions of standard values

Room temperature	T_{RT} defined as 23 °C ± 5 °C
Humidity	RH = 25 % to 75 % relative humidity (in accordance with IEC 60068-1)
Test temperature	T_{RT}

4.5 Thermal equilibrium

A component exposed to a constant ambient temperature under defined operating conditions is regarded as continuous temperature controlled when the temperature of any part of the component has not deviated from the target temperature by more than 5 K at any point in time.

The time until this thermal equilibrium is reached shall be defined experimentally by the manufactures and specified in the testing documentation. In case of temperature cycling tests, after reaching the specified temperature benchmark value for continuous-temperature control, the units under test shall additionally be held for a defined time to allow mechanical stress to place strains on the components. This additional holding time is specified for the respective test.

4.6 Sampling rates and measured value resolutions

The sampling rate and bandwidth of the measuring system shall be adapted to the respective test. All measured values with all maximum values (peaks) shall be recorded.

The resolution of the measured values shall be adapted to the respective test. It shall be guaranteed that voltage peaks that occur do not lead to overflow or are not measurable if the resolution is too low. Data reduction/abstraction (e.g. limit value monitoring) shall not suppress anomalies.

When the measured values for the lifetime tests are defined, it shall be ensured that the measured values are recorded with sufficient granularity with respect to the expected lifetime to ensure that the End-of-Life can be determined reliably and precisely.

4.7 Parameter test

The parameter test is intended for the characterisation of the electrical and mechanical characteristics of the units under test before (to ensure that only faultless units under test are entered into qualification tests) and after the individual test sequences. It should yield information about the characteristic parameters of the capacitors, which may vary due to variations in production and the stress they are exposed to during the individual tests. Unless otherwise stated, the individual test steps of the parameter tests shall be conducted, documented and the deviations from the specified tolerances evidenced before and after the individual test respectively.

The objective of the measurements and tests is to:

- ensure the absence of defects of all units under test;
- ensure the fulfilment of all the requirements;
- prove the functional behaviour and the accuracy of all functions;
- characterise the units under test.

4.8 Physical analysis

The physical analysis is a detailed analysis of failed parts.

The physical analysis of successfully tested parts is performed according to individual agreement between parties.

Proceed as follows:

- perform and document the non-destructive tests/analyses;
- identify/coordinate further tests/analyses with the specialist client department responsible on the basis of the results of the non-destructive tests/analyses;
- perform and document the destructive tests/analyses;
- archive the specimens and damaged parts.

The change in the unit under test comparable with initial conditions shall be evaluated. The results shall be documented in the test report.

4.9 Restriction on performance

The test lab shall be organised and operated in accordance with ISO/IEC 17025. All test equipment used for measuring shall be calibrated in accordance with ISO/IEC 17025 (or as is specified or recommended by the manufacturer), and based on the National Institute of Standards (e.g. in Germany PTB; National Metrology Institute of Germany) or another equivalent national test lab. The test devices, workshop equipment, installations and testing procedures used shall not distort the behaviour of the unit under test. These shall be documented in the test report together with the precisions and the calibration expiration date.

5 Electrical characterisation

5.1 General

The objective of the electrical characterisation is to determine changes in the electrical parameters due to the tests carried out. The measurements shall therefore be performed in the same way before and after the tests.

5.2 E-01 Capacitance

5.2.1 Purpose

The measurement is intended to determine the capacitance of the unit under test.

5.2.2 Test

The measurement shall be carried out with the following parameters:

– test temperature T_{RT};
– test voltage small signal measurement;
– frequency 100 Hz (120 Hz) or 1 kHz, optional 10 kHz as agreed with the user.

NOTE The capacitance value can slightly vary, when measured with different frequencies.

5.3 E-02 insulation resistance between terminals

5.3.1 Purpose

The measurement is intended to determine the insulation resistance of the unit under test.

5.3.2 Test

The measurement shall be carried out with the following parameters:

– test temperature T_{RT} and T_{max};
– test voltage U_{RDC};
– frequency 0 Hz (DC);
– measurement time 60 s after the test voltage is reached.

5.4 E-03 ESR

5.4.1 Purpose

The measurement is intended to determine the equivalent series resistance of the unit under test at the terminal in accordance with the measuring point in the data sheet.

5.4.2 Test

The measurement shall be carried out with the following parameters:

– test temperature T_{RT};
– test voltage small signal measurement;
– frequency 1 kHz, 10 kHz, 20 kHz or in accordance with the data sheet.

5.5 E-04 ESL

5.5.1 Purpose

The measurement is intended to determine the equivalent series inductance of the unit under test at the terminal in accordance with the measuring point in the data sheet.

5.5.2 Test

The measurement shall be carried out with the following parameters:

– test temperature T_{RT};
– test voltage Small signal measurement;
– frequency 1 MHz (reference value); optional 10 MHz, 30 MHz, up to 100 MHz as agreed with the user.

5.6 E-05 External insulation terminal to case

5.6.1 Purpose

The measurement is intended to test the insulation strength of the unit under test against the environment. If the unit under test has a metal case, the test shall be performed between the case and the electrically interconnected connections.

For capacitors in a non-metallic case, a metal foil shall be fixed to the body of the capacitor at positions as agreed between the manufacturer and the user, considering the required creepage distance and clearance. The test voltage shall be applied between inner connections and the foil.

5.6.2 Test

The measurement shall be carried out with the following parameters:

– test temperature T_{RT};
– Test voltage U_t U_{RDC} ≤ 60 V: 750 V;
– U_{RDC} ≤ 500 V 2 830 V;
– U_{RDC} > 500 V $\sqrt{2} \times (2 \times U_{RDC} + 1\,000)$ V;
– frequency 0 Hz (DC);
– duration of test 60 s in each polarity.

If Y-capacitors are integrated into a DC-link capacitor unit, test details and test voltages shall be agreed between manufacturer and user under consideration of the insulation requirements for the Y-capacitors and the DC link capacitor.

6 Mechanical characterisation

6.1 M-01 Geometry

6.1.1 Purpose

The measurement is intended to determine the geometric data of the unit under test related to the drawing. All measured values shall be within the specified tolerances.

At least length, width, height as well as the position of the electrical and mechanical connections shall be measured for the mechanical characterisation. Electrical or mechanical connections, which are intended to be deformed during measurement or testing can be omitted from that measurement, if agreed between manufacturer and user.

6.1.2 Test

The measurement shall be carried out with the following parameters:

– Test temperature T_{RT}

6.2 M-02 Visual inspection

6.2.1 Purpose

This test is intended to evaluate the appearance of the unit under test.

The visual inspection should detect anomalies such as cracking in the potting and housing, corrosion of the connections, etc. A photograph shall be included in the test report in a resolution corresponding to the current state-of-the-art.

6.2.2 Test

The measurement shall be carried out with the following parameters:

– Test temperature T_{RT}

7 Environmental and exposure tests

7.1 B-01 Thermal shock

7.1.1 Purpose

This test simulates the component element's thermal exposure to shock-like temperature changes during vehicle operation. It is intended to validate the component element in terms of fault profiles, such as cracking, delamination and short circuits due to thermal changes.

7.1.2 Test

The test shall be performed in accordance with IEC 60068-2-14, Na with the following parameters:

– lower test temperature −40 °C;
– upper test temperature T_{max};
– number of cycles 1 000;
– holding time at least 5 min after thermal equilibrium;
– test voltage none.

7.2 B-02 Damp heat, steady state

7.2.1 Purpose

This accelerated test simulates the exposure of the component element to damp heat during the vehicle service life. The test is intended to validate the quality and reliability of the component element to faults caused by damp heat such as corrosion, migration/ dendrite growth, swelling and degradation of plastics.

7.2.2 Test

The test shall be performed in accordance with IEC 60068-2-78 with the following parameters:

– test temperature 65 °C;
– test humidity 93 % RH, no condensation;
– duration of test 1 750 h (reference condition);
– test voltage 1 700 h without U_{RDC} 50 h of the test time with U_{RDC} at the end of the test.

NOTE Deviating (more severe) test conditions can be required by users.

7.3 B-03 High temperature load

7.3.1 Purpose

The accelerated test condition A and condition B simulate the thermal exposure of the component elements during the vehicle service life under overload and normal operating conditions. They are intended to validate the quality and reliability of the component element with respect to faults that occur due to thermal exposure such as diffusion, migration and oxidation.

The total test time, combination and duration of overload condition A and operating life condition B shall be determined and agreed between manufacturer and user under consideration of acceleration factors and the time-voltage profile. For example, condition A and condition B may be combined in a way, that a part of the duration of condition A is performed in the beginning phase of the test (e.g. after 168 h or 500 h) as pre-conditioning of the test specimen by overload, and the other part of the duration at the end of the test. With such a combination the impact of overload conditions to reliability and the performance of the capacitor to withstand such overload conditions at the end of service life can be validated.

7.3.2 Condition A: high temperature – overload

The test shall be performed in accordance with IEC 60068-2-2 with the following parameters:

– test temperature T_{max};
– duration of test as calculated from time-voltage profile;
– applied voltage U_{max}.

U_{max} and the duration of test (for example 100 h as a typical value) shall be agreed between manufacturer and user under consideration of the mission profile of the system. Deviating overload conditions may be agreed between manufacturer and user under consideration of voltage derating in case T_{max} is exceeded.

7.3.3 Condition B: high temperature – operating life

The test shall be performed in accordance with IEC 60068-2-2 with the following parameters:

– test temperature T_{max};
– duration of test as agreed between manufacturer and user;
– applied voltage U_{RDC}.

U_{RDC} and the duration of test (for example 1 000 h or 2 500 h as typical values) shall be agreed between manufacturer and user under consideration

- of the mission profile of the system,
- of voltage and temperature acceleration factors specific for the capacitor technology,
- of an appropriate safety margin to validate the performance of the capacitors during the vehicle service life.

7.4 B-04 Vibration

7.4.1 Purpose

This test simulates the exposure of the component element to vibrations during automotive operation. It is intended to validate the component element's durability with regards to fault profiles such as component detachment and material fatigue.

The actual stress conditions can vary by vehicle model or type and the place of installation. Normally the validation test conditions shall be agreed between manufacturer and user. The typical profile given in 7.4.2 can be used if nothing is specified by a user.

7.4.2 Test (typical profile)

The units under test shall be fixed to the designated areas and the terminals shall be connected close to reality. See IEC 60068-2-47 for guidance. The test shall be performed in accordance with IEC 60068-2-64 with the parameters specified in Table 5:

– test temperature T_{RT};
– excitation broadband random vibration;
– test duration for each spatial 8 h;
– RMS value of acceleration 30,8 m/s^2;
– test voltage no voltage.

Vibration profile see Figure 1 below.

Table 5 – Parameters of the vibration profile

Frequency Hz	Power density spectrum $(m/s^2)^2/Hz$
5	0,884
10	20
55	6,5
180	0,25
300	0,25
360	0,14
1 000	0,14
2 000	0,14
NOTE See also ISO 16750-3:2023, 4.1.2.4 and ISO 19453-3:2018, 4.1.2.2.	

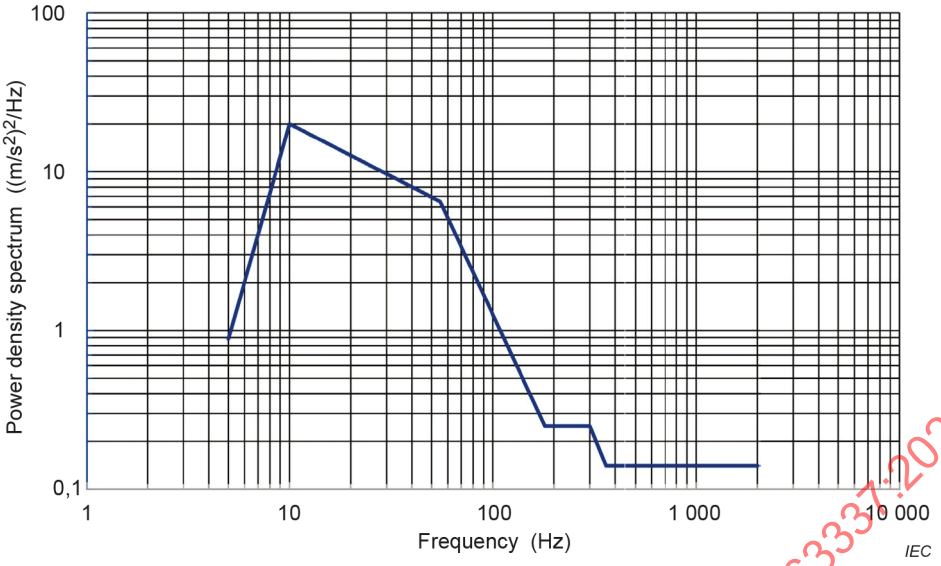


Figure 1 – Vibration profile

7.5 B-05 Charge/ discharge test

7.5.1 Purpose

These tests simulate the charging and discharging behaviour of the capacitor. This test shall detect possible damages to the contacts inside the capacitor. Details of the test and test conditions shall be agreed between manufacturer and user.

7.5.2 Test

The test shall be carried out in accordance with IEC 60384-1-2021, 6.11 with the following parameters:

– Charging voltage as specified to realize the required $(\mathrm{d}U/\mathrm{d}t)_{\mathrm{pulse}}$ of the discharge pulse;
– Charging time < 0,63 s;
– Repetition rate 1 cycle per second;
– Number of cycles 10 000 (charge/discharge cycles);
– $(\mathrm{d}U/\mathrm{d}t)_{\mathrm{pulse}}$ as agreed between manufacturer and user;
– Test temperature T_{RT}.

7.6 B-06 Short-circuit test

7.6.1 Purpose

These tests simulate the short circuit behaviour of the capacitor. Details of the test and test conditions shall be agreed between manufacturer and user.

7.6.2 Test

The test shall be carried out in accordance with IEC 61071:2017, 5.9 with the following parameters:

– Charging voltage as specified to realize the required $(dU/dt)_{short}$ of discharge pulse;
– Number of cycles 5 (unless otherwise agreed between manufacturer and user);
– Condition 2 minutes pause between charges;
– Test temperature T_{RT};
– $(dU/dt)_{short}$ as agreed between manufacturer and user.

7.7 Acceptance criteria

The following parameters and their drift shall be determined before and after each environmental or exposure test:

1) capacitance;
2) ESR;
3) insulation resistance.

All values shall be within specification (data sheet). The data sheet should contain rated values and their limits for the delivery condition and regarding the service life (the limits for the delivery condition and service life may be different).

The parameters shall be determined in accordance with Clause 5, Electrical characterisation.

8 Test sequence diagram

The test sequence is shown in Figure 2; it is performed with 6 parts per path.

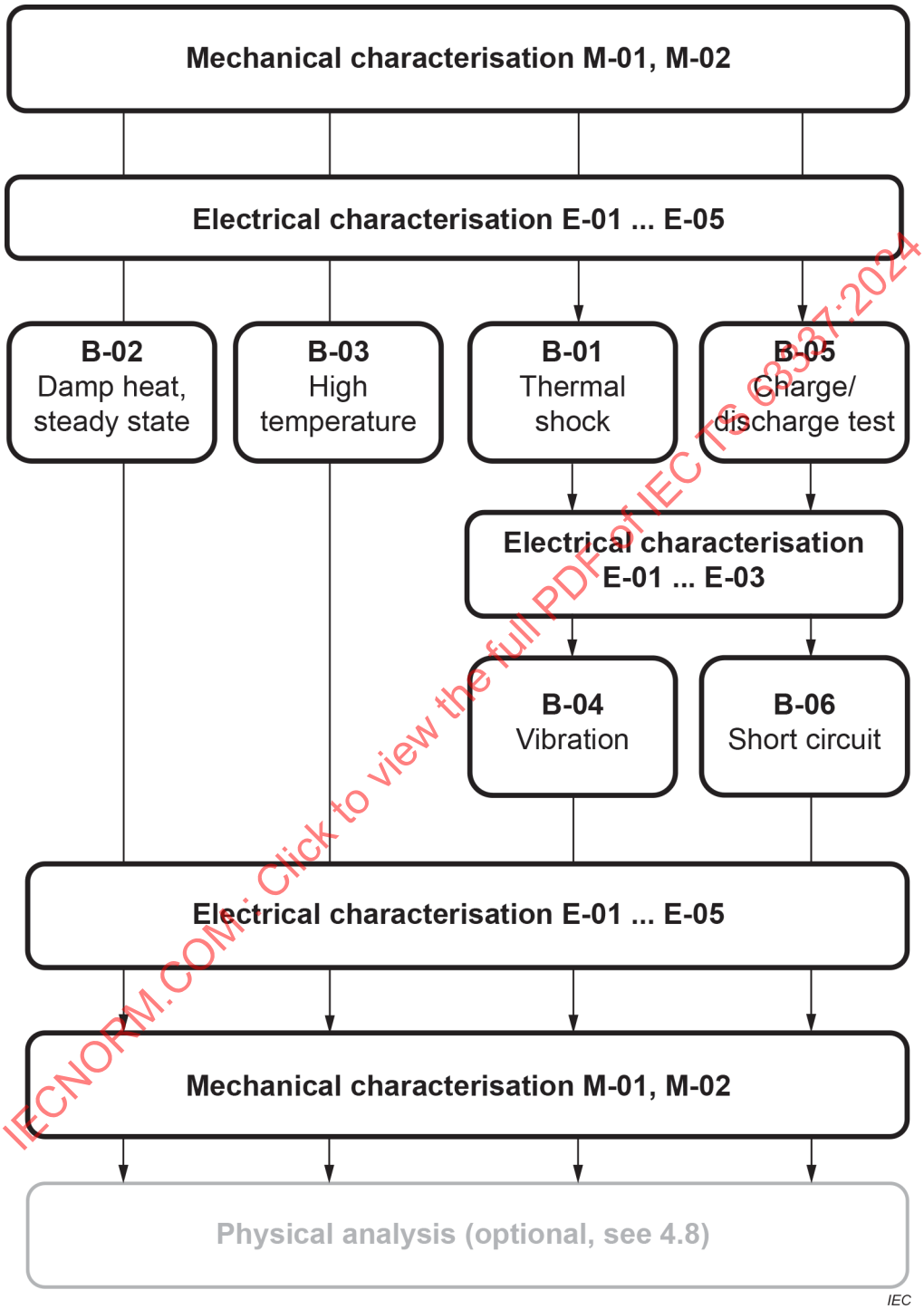


Figure 2 – Test sequence

9 Flammability (if required)

The materials used for case and potting shall be self-extinguishing. The necessity of test, the test methods, test samples and severities shall be agreed between manufacturer and user.

If not otherwise specified by the relevant specification, the tests, if required, shall be performed either in accordance with:

- IEC 60695-11-10; classification V-1, HB

or in accordance with

- IEC 60695-2-12; glow-wire test temperature 750 °C.

Annex A
(informative)

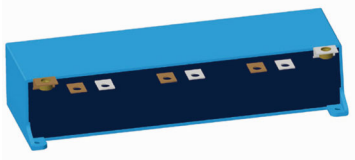
Example data sheet

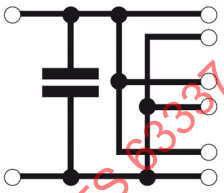
This sample data sheet serves only as an illustrative example. It is up to the manufacturer to add or omit data.

Data sheet

Capacitor: ABCDEF 05507a000

Customer: _____





Characteristic values:

Parameters	Condition[a]	Min.	Type	Max.	Unit
Nominal capacitance C_N				500	µF
C_N tolerance		-5		10	%
Peak voltage U_{pk} Rated voltage U_N	T_{max} $T_{min} \leq T_{amb} \leq T_{op}$			500 470	VDC VDC
Insulation resistance R_{iso} between the terminals External insulation terminal to case	$U = U_N$; 60 s no breakdown; 60 s per polarity	20 2 830			MΩ VDC
ESR 1 kHz				0,4	mΩ
ESR 10 kHz ESR 20 kHz ESL 1 MHz T_{max} (C charged) I_R (endurance test) dU/dt_{pulse} dU/dt_{short} Length Width Height Weight	 OA; U_N Convection cooling; T_{amb} = 80 °C; 20 kHz sinusoidal; no additional heat input via thermal conduction or radiation 10 000 pulses 5 pulses		 250 70 50 1 250	1,0 1,4 15 110 150 [b] [c] 	mΩ mΩ nH °C Arms V/µs V/µs mm mm mm g

[a] T_{amb} = T_{RT}' unless otherwise specified.

[b] See manufacturer specification

[c] See manufacturer specification

Data sheet

Capacitor: ABCDEF 05507a000

Customer: _____

Performance in the environmental/exposure tests:

B-01 Thermal shock + B-04 Vibration

Performance

$\lvert\Delta C/C_0\rvert$	**ESR**	**ESR**	**ESR**	**ESL**	R_{iso}
1 kHz	1 kHz	10 kHz	20 kHz	1 MHz	DC
< 5 %	< 2 mΩ	< 4 mΩ	< 6 mΩ	< 30 nH	> 50 MΩ

B-02 High damp heat, steady state

Performance

$\lvert\Delta C/C_0\rvert$	**ESR**	**ESR**	**ESR**	**ESL**	R_{iso}
1 kHz	1 kHz	10 kHz	20 kHz	1 MHz	DC
< 4 %	< 1 mΩ	< 2 mΩ	< 3 mΩ	< 25 nH	> 50 MΩ

B-03 High temperature

Performance

$\lvert\Delta C/C_0\rvert$	**ESR**	**ESR**	**ESR**	**ESL**	R_{iso}
1 kHz	1 kHz	10 kHz	20 kHz	1 MHz	DC
< 3 %	< 1,5 mΩ	< 3 mΩ	< 4,5 mΩ	< 25 nH	> 50 MΩ

B-05 Charge/discharge test + B-06 Short-circuit test

Performance

$\lvert\Delta C/C_0\rvert$	**ESR**	**ESR**	**ESR**	**ESL**	R_{iso}
1 kHz	1 kHz	10 kHz	20 kHz	1 MHz	DC
< 5 %	< 1 mΩ	< 2 mΩ	< 3 mΩ	< 15 nH	> 50 MΩ

Additional manufacturer specifications

Annex B
(normative)

Guideline for qualification in case of changes

B.1 General

Short product and technology cycles as well as new environmental regulations ("Pb-free", flame retardants, ….) frequently result in process and material changes of components, printed circuit boards, assembly techniques and circuit layout which have to be evaluated.

The ZVEI "Guideline for Customer Notifications of Product and /or Process Changes (PCN) of Electronic Components specified for Automotive Applications" describes an appropriate methodology for dealing with changed electronic components. The table below in this guideline presents recommendations for how to assess typical changes of electronic components. These recommendations promote an open risk-based discussion between supplier and customer regarding qualifications.

This document adapts the structure of the Delta Qualification Matrices developed by the ZVEI Working Group "PCN-Methodology", but it is not a part of the official documentation (Link to the official PCN-Documents of the ZVEI: https://www.zvei.org/ PCN). Actual contents represent state-of-the-art technology and does not claim to be comprehensive. Deviation from proposed guideline shall be mutually agreed as customer specific requirements have to be considered.

B.2 Basic Qualification-Table Application (completion by component manufacturer)

- This table shall be used for changes only. The table is not applicable for new product or special qualifications (for instance for encapsulation of module).
- If a change is not listed in this table, the qualification plan shall be defined and agreed between customer and supplier.
- In case of deviations from tests, which should be considered this should be notified and commented by the component manufacturer in the area "Reason for exception of tests". Test results in form of generic data (G) are allowed when notified and justified.

B.3 Evaluation Levels are categorized as follows

B.3.1 Categories

- "C: Component level": The evaluation of a change at component level by the component manufacturer is sufficient. Generic data from other relevant evaluations can be used.
- "A: Application level": The intended change described in the PCN may influence the properties of the application (e.g. Electronic Control Unit). In addition to the evaluation under C the influence of the change in the application is evaluated by suitable investigations by the customer. The scope of the evaluation shall be aligned with the OEM. It shall be considered whether the application / assembly requirements are already sufficiently safeguarded by other qualifications (application specific risk assessment).
- "*: will become A/C after decision": is subject to a case-by-case evaluation.
- "**: Not relevant for qualification matrix": Changes which fulfil neither A nor C definitions.

B.3.2 Important notes

- Tests identified by the table have to be considered and checked if they are necessary to assess the specific change. Test modifications or generic data have to be justified in detail.
- Categories, comments and notes need attention, as they provide important hints and limitations.

Disclaimer:

This document adapts the structure of the Delta Qualification Matrices developed by the ZVEI Working Group "PCN-Methodology", BUT IT IS NOT PART OF THE OFFICIAL DOCUMENTATION

(Link to the official PCN-Documents of the ZVEI:

https://www.zvei.org/PCN).

I = Information Note required
P = PCN required
-- = Not required

	Assessment of impact regarding following aspects – contractual agreements – technical interface of handling/processability/manufacturability of customer – form, fit, function, quality performance, reliability	**Potential impact?** No	Yes	Understanding of component experts	Examples to explain	Evaluation level A / C A: Application level C: Component level *: will become A/C after decision **: Not relevant for qualification matrix	Further applicable conditions	Line evaluation (can be evaluated by data or audit/on site check	Check of specification (for raw material only	Thermal Shock (linked with B-04 Vibration) B-01	Damp Heat, Steady State B-02	High Temperature B-03	Vibration (linked with B-01 Thermal Shock) B-04	Charge/Discharge Test (linked with B-06 Short-Circuit Test) B-05	Short-Circuit Test (linked with B-05 B-06	Geometry M-01	Visual Inspection M-01	Electrical Characterisation E-01 bis E-05	Remarks
	Type of change	No	Yes																
	DC-LINK FILM CAPACITORS																		
	Any																		
DCL-FLM-AN-01	Any change with impact on special customer characteristics/contractual agreements	P	P		Not relevant for technical evaluation.	**		-	-	-	-	-	-	-	-	-	-	-	
DCL-FLM-AN-02	Any change with impact on technical interface or processability/manufacturabiliy of customer	P	P		Technical interface means component terminals.	**A**		-	-	-	-	-	-	-	-	-	-	-	

	DATASHEET / SPECIFICATION																		
DCL-FLM-DS-01	Change of electrical/mechanical parameters or drawing	P	P	Change of application relevant information **Not included:** Editorial changes.	e.g. tighten of electrical parameter distribution	**A**	Risk assessment depending on change for each application.	-	-	-	-	-	-	-	-	-	-		
DCL-FLM-DS-02	Correction of data sheet / specification	I	P	No technical change of the product, only correction in description (wording, drawing, ...) (I): In case of editorial changes. (P): In case of impact on product integrity.	e.g. data sheet correction because of new information about component behaviour	**		-	-	-	-	-	-	-	-	-	-	-	
DCL-FLM-DS-03	Specification of additional parameters	I	P	Description of a new not previously covered parameter. No technical change of the product. (I): no influence (P): Risk assessment depending on change for each application to provide evidence of additional parameters (stat. evaluation)	e.g. adding new (tested) parameter.	**C**		-	-	-	-	-	-	-	-	-	-	-	

	MATERIAL OR SUPPLIER																	
DCL-FLM-MA-01	Change of material composition or change of supplier – Sealing Compound	P	P	Typically change within epoxy or PU sealing without effect to mechanical properties. Note: Change from epoxy sealing into PU sealing (both direction) will lead to generate a new product.	e.g. change of epoxy or PU composition	C	A: in combination with DCL-FLM-DS-01 or if change of sealing compound with effect to mechanical properties.	-	•	•	•	•	•	•	•	•	•	•	
DCL-FLM-MA-02	Change of material composition or change of supplier – Package	P	P	Change material of package	Change material of package, e.g. change from PBT to PPS e.g. change of glass fiber ratio	C		-	•	•	•	•	•	-	-	•	•	•	
DCL-FLM-MA-03	Change of material composition or change of supplier – Terminals	P	P	Change of Terminals (e.g. Busbar) without impact to characteristics If change of lead frame material leads to an ESR change, then change of data sheet (DCL-FLM-DS-01) has to be respected.	e.g. change of basis material from Cu to Fe e.g. change of finishing from SnPb to Sn	C A	A: in combination with DCL-FLM-DS-01	-	•	•	•	-	•	•	•	•	•	•	
DCL-FLM-MA-04	Change of material composition or change of supplier – Raw Material for Metal Spray (Schoop)	P	P	Change of Raw Material for Metal Spray (Schoop): Use different material for metal spray process for boxed and naked types	e.g. change of spray metal wire	C		-	•	•	•	•	•	•	•	-	-	•	
DCL-FLM-MA-05	Change of material composition or change of supplier – Base film / dielectric material	P	P		e.g. change of additives (<1%) of film composition (same raw material)	C		-	•	•	•		-	•	•	-	-	•	
DCL-FLM-MA-06	Change of material composition or change of supplier – Metallization	P	P		e.g. change from Al to Zn or Al-Zn ratio	C		-	•	•	•	•	-	•	•	-	-	•	
DCL-FLM-MA-07	Any changes of further materials or change of supplier	I	P			C	*2: test to be mutually agreed		•	*2	*2	*2	*2	*2	*2	*2	*2	*2	

	DESIGN																			
DCL-FLM-DE-01	Changes of terminal (surface finish, shape, colour, appearance or dimension structure – Busbar Dimensions / Thickness / Terminal Area)	P	P	Change of busbar dimension	e.g. change of drill holes, e.g. change of thickness of terminal	**A**	Visual inspection only on outside surface	-	-	●	-	-	●	●	●	●	●	●		
DCL-FLM-DE-02	Change of mechanical dimensions	P	P	Change of fix points of terminations or housing	e.g. measures, drill holes	**A**		-	-	-	-	-	●	-	-	●	●	-		
DCL-FLM-DE-03	Changes of inner construction – Inner Connection	P	P	Change of inner connection	e.g. change from soldered connection to welded connection e.g. changed connection to schoop layer e.g. change of inner construc-tion of housing	**C**		-	-	●	●	-	●	●	●	-	-	●		
DCL-FLM-DE-04	Changes of appearance	I	P	Change of appearance. (I): Change in appearance without impact on product integrity. (P): Change in appearance with impact on product integrity. Note: Marking on device is defined as separate change (DCL-FLM-PV-02).	e.g. change or adding of colour on component	**C**	**Check if MATERIAL is affected.**	-	-	-	-	-	●	-	-	●	●	●		
DCL-FLM-DE-05	Changes of inner construction – Film	I	P	Change of film design	e.g. change to a different film supplier/metallization profile	**C**	**A: in combination with DCL-FLM-DS-01**	-	●	●	●	●	-	●	●	-	-	**B**		
DCL-FLM-DE-06	Changes of inner construction – Insulation System	I	P	Change of inner insulation to protect winding element against housing.	e.g. change of potting material e.g. change of number of inner insulation layers (depending of insulation material thickness)	**C**		-	●	●	●	●	●	-	-	-	-	**B**		
DCL-FLM-DE-07	Changes of housing (surface finish, colour, appearance)	I	P	Change of housing	e.g. change of surface	**C**		-	-	●	●	-	●	-	-	●	●	-		

	PROCESS																		
DCL-FLM-PR-01	Changes in process technology or manufacturing methods – Assembly	I	P	Change of resin filling or hardening process	e.g. change in resin filling process (mixing, sequences, potting, …) e.g. change in hardening process (temperature, time, …)	**C**		•	-	•	•	•	•	-	-	-	•	-	
DCL-FLM-PR-02	Changes in process technology or manufacturing methods – Terminal Attach	I	P	Change Terminal Attach Process to winding element	e.g. spraying e.g. welding / soldering	**C**		•	-	•	•	•	•	•	•	-	-	**B**	
DCL-FLM-PR-03	Changes in process technology or manufacturing methods – Winding	I	P	Change of winding, flattening or tempering process	e.g. change of tempering temperature	**C**		•	-	•	•	•	-	•	•	-	-	**B**	
DCL-FLM-PR-04	Tuning of process parameter within specification	-	P	Variation within process specification.	e.g. process optimization	**C**		-	-	-	-	-	-	-	-	-	-	-	
DCL-FLM-PR-05	Any further changes of process technology or manufacturing methods	I	P	change of process	e.g. change of machinery or tools	**C**	***2: test to be mutually agreed**		•	*2	*2	*2	*2	*2	*2	*2	*2	*2	
	PACKING / SHIPPING – NEW MATERIAL, CRITICAL DIMENSIONS																		
DCL-FLM-PN-01	Packing / shipping specification change (loosening of tolerances), carrier change, labelling, product marking	P	P	Change of packing specification.		**	customer specific agreement	-	-	-	-	-	-	-	-	-	-	-	
DCL-FLM-PN-02	Dry pack requirements change	P	P	Change of drypack requirements.	e.g. change of MSL e.g. change in dry pack assurance (HIC, MBB)	**		-	-	-	-	-	-	-	-	-	-	-	
DCL-FLM-PN-03	Change of carrier (tray)	P	P	Change of carrier	e.g. change by material e.g. change by geometry.	**		-	-	-	-	-	-	-	-	-	-	-	

	PACKING / SHIPPING – VISUAL INSPECTION																		
DCL-FLM-PV-01	Change of labelling	I	P	Change of labelling	(I) e.g. additional information (RoHS stamp) (P) e.g. change of customer specific information	**		-	-	-		-	-	-	-	-	-	-	
DCL-FLM-PV-02	Change of product marking	I	P	Marking on device.	e.g. change of content of marking e.g. change of method of marking e.g. change of appearance of marking	**		-	-	-	-	-	-	-	-	-	-	-	
DCL-FLM-PV-03	Change of packing/shipping specification	P	P	Change in packing specification which does not describe a change of dimensions or material of the packing.	e.g. change of documentation in packing specification	**		-	-	-	-	-	-	-	-	-	-	-	