This initial feedback is submitted on behalf of participants in the Umbrella Project ("UP")´s Exemption #7c-II technical Working Group ("WG") (hereafter referred to as "UP Exemption #7c-II WG Participants").

Answers to the questions and additional comments have been inserted into the document in dark teal color.

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Clarification Questionnaire Exemption 7(c)-II

Exemption for „Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher "

Abbreviations and Definitions

AC	Alternating Current
CO_2 emissions	Carbon dioxide
DC	Direct current
EEE	Electrical and Electronic Equipment
GDP	Gross domestic product
LCA	Life cycle assessment
Pb	Lead
RoHS	Directive 2011/65/EU on the Restriction of Hazardous Substances in Electrical and Electronic Equipment
Umbrella Project	A large number of company/business organizations/business associations that are participants in the RoHS Umbrella Industry Project
V	Volt

Background

The Oeko-Institut has been appointed by the European Commission, within a framework contract[1], for the evaluation of applications for exemption from Directive 2011/65/EU (RoHS), to be listed in Annexes III and IV of the Directive.

Your organisation (Murata Electronics Europe B.V) has, on behalf of the participants in the RoHS Umbrella Industry Project, submitted a request for the renewal of the above-mentioned exemption, which has been subject to an initial evaluation. A summary of the main argumentation for justifying the request is provided below as a first basis to be used in the stakeholder consultation planned as part of this assessment.

Please review the summary of the argumentation provided to ensure that your line of argumentation has been understood correctly and provide answers to the questions that follow that are to address aspects requiring additional information and/or clarification.

[1] The contract is implemented through Framework Contract No. ENV.B.3/FRA/2019/0017, led by Ramboll Deutschland GmbH.

1. Summary of argumentation of applicant on the justification of the exemption

1.1. Background

The current state of technology is that most ceramic capacitors are already produced from lead-free materials. However, for some applications, capacitors are needed that provide specific properties. High voltage rating ceramic capacitors require a dielectric material that provides high dielectric constant at high operating voltage. High dielectric constant and low leakage at high temperatures are necessary properties of the material in order to obtain components with high energy storage capability. Such properties can currently only be achieved by using lead titanate as a constituent of the dielectric ceramic.

Murata Electronics Europe B.V, on behalf of the RoHS Umbrella Industry Project requests the extension of the existing exemption with its current wording for the maximum duration allowed by Article 5 of the Directive.

Comment by UP Exemption #7c-II WG Participants:

The original application submitted December 19th, 2019 has been extended to cover Category 11 (submitted October 9th, 2020), in addition to Categories 1-10.

"Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher"	Does not apply to applications covered by point 7(c)-I and 7(c)-IV of this Annex. Expires on: — 21 July 2021 for categories 1-7 and 10; — 21 July 2021 for categories 8 and 9 other than in vitro diagnostic medical devices and industrial monitoring and control instruments;

The applicant addresses lead-containing ceramic capacitors for a rated voltage of 125 V AC or 250 V DC or higher. Such capacitors are used in various categories of EEE, including consumer and household equipment as well as monitoring and control instruments in industry and medical devices. Discrete ceramic capacitors for high voltage are used in high voltage electronic circuits, usually power electronic inverters, power electronics and specific appliances.

The Umbrella Project asserts, that there are currently no alternative materials available that provide the same combination of dielectric properties and thermal stability as lead titanate. Up to now and within the foreseeable future, alternatives to allow substitution are not expected to become available on the market. Thus, the applicant asks for an extension of the existing exemption in RoHS annex III for the respective maximum validity periods foreseen in the RoHS2 Directive.

1.2. The history of the exemption and a starting point for the current assessment

The exemption for lead in dielectric ceramic capacitors has been evaluated twice since the Directive 2002/96/EC (RoHS 1) was first published in 2003. The original exemption 7d was entitled "*Lead in electronic ceramic parts (e.g. piezo electronic devices)*". In 2008/2009, the first review of this exemption concluded that lead can be substituted in low voltage dielectric ceramic capacitors. As a consequence, a change in the title and the number of the exemption was adopted to the Annex of RoHS 1. Since then, high voltage capacitors were addressed by the new exemption 7(c)-II entitled: "*Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher*". The low voltage ceramic capacitors were addressed by exemption 7(c)-III entitled: "*Lead in dielectric ceramic in capacitors for a rated voltage of less than 125 V AC or 250 V DC*". Exemption 7c-III was transferred without changes from the Annex of RoHS 1 to Annex III of RoHS 2 and expired on 1 January 2013 because lead-free alternatives have become available for low-voltage ceramic capacitors.

Exemption 7c-II was transferred without changes from the Annex of RoHS 1 to Annex III of RoHS 2 because lead-free alternatives were not available for high voltage dielectric ceramic capacitors. In 2015, Murata Elektronik GmbH applied for a further extension of exemption 7c-II. A change in the wording of exemption 7c-II was requested to disambiguate the scope from exemption 7(c)-I.

The assessment of the request (Gensch et al. 2016) concluded that the exemption was still justified as substitutes were not available for application in high voltage ceramic capacitors. However, the extension of the exemption was recommended for only three years because the applicant could not demonstrate that the substitution of lead in the applications concerned was scientifically and technically impracticable. The 2016 evaluation concluded that “*Should industry fail then again to provide substantiated information about specific research and available lead-free HVC in the future, the consultants recommend cancelling the exemption in the next review*.” The wording of the exemption has not changed since 2016.

The present request, submitted on 19 December 2019 by Murata Elektronik GmbH on behalf of 37 industry organisations, aims at extending the existing exemption for lead in high voltage ceramic capacitors for the second time (Murata Electronics Europe B.V. 2019). A change in the wording is not proposed again.

1.2.1. Volume of lead to be placed on the EU market through the exemption

According to the applicants, there is an annual amount of **7 t** of lead placed on the EU market in the form of lead titanate ceramics as a constituent of capacitors, used in EEE (Murata Electronics Europe B.V. 2019). The amount is calculated based on economic allocation of global amounts to the EU market (global GDP ratio of Europe (22%).

The previous exemption request from 2015 estimated the amount of lead placed on the EU market in the form of ceramic capacitors (as of 2013) as 11.3 tons per year. This was already a lower amount compared to 30 t of lead placed on the EU market in the same application area in 2007.

1.3. Technical description

Discrete ceramic high voltage capacitors (>= 125 V AC / 250 V DC) are incorporated in a wide range of EEE to store and release electric charges, which is necessary for the products to function as needed. The capacitors provide their function (capacitance) in high voltage circuits and withstand also elevated temperature without drop in energy storage capability and leakage of the stored charge.

Application areas of high-voltage capacitors are mainly power supply devices and protection devices that are part of almost all types of EEE, including:

- Large and small household appliances;
- IT and telecommunications equipment;
- consumer equipment;
- lighting equipment;

- electrical and electronic tools;
- toys, leisure and sports equipment;
- automatic dispensers;
- industrial monitoring and control instruments and other specific EEE, such as power electronic inverters, pulsed power electronics, pulse forming networks, capacitive discharge units, transient high voltage suppression, magnetization/demagnetization devices, plasma generators, high-energy flash lamps, radio frequency interference suppression and electrical safety devices.
- medical devices, including in-vitro diagnostics, other medical devices or other monitoring and control instruments than those in industry;

The RoHS substance in question – lead - influences the electrical properties of the solid-state dielectric (ceramic material), in particular capacitance and dielectric losses of capacitors. The ceramics contain lead in concentrations of 0.1- 60 wt% (%weight) of the homogeneous material.

Lead-containing ceramic high voltage capacitors are explained to be indispensable components in EEE that provide stable electric properties even at high voltage and frequencies as well as elevated temperatures.

1.4. Applicant’s justification for the requested exemption

Murata Elektronik GmbH explains that, to date, no lead-free dielectric ceramics have been found for high-voltage capacitor applications that have the required technical characteristics (Murata Electronics Europe B.V. 2019). According to the applicant, lead-free substitutes are not considered to provide the same performance compared to lead-containing ceramics, specifically:

- High dielectric constant at high operating voltage,
- High energy storage capability (also at high temperatures);
- Low leakage at high voltage and high temperatures; and
- Low loss at high current, frequency, and temperatures.

The applicant asserts that since 2015, industry, represented by the Umbrella Project, has been investigating the availability of lead-free materials that could replace lead in dielectric ceramics. Thus far, no technical alternative has been found for this application and there are no indications that lead-free ceramic materials will be found for high-voltage capacitors in the near future.

The exemption request specifies the unique properties of lead-containing dielectric ceramics, which makes their use in high voltage capacitors indispensable:

- Low Energy Loss Properties: The use of leaded ceramic suppresses thermal vibration of the dielectric material, especially if high-frequency alternating currents are applied. Lead-free dielectrics vibrate stronger at high-frequencies and thus cause larger energy dissipation in form of heat. This would be detrimental to the proper function of modern telecommunications and computing equipment that work at high frequency.
- Thermal Properties: Leaded dielectric ceramics exhibit both low capacitance variation with temperature changes and high Curie temperatures (above 130°C). Lead-free materials do

not allow the design of high-voltage devices for high-temperature operating conditions because the capacitance decreases at higher temperature.

- Capacitance: At a high voltage, the dielectric is subject to mechanical stress due to its piezoelectric properties. This effect (electrostriction) causes lead-free dielectric ceramics to become destabilized and in the worst case lose its functions. In contrast, Lead-containing dielectric ceramics suppress this effect so that they can be safely used for high-voltage devices even if they have high capacitance.

1.4.1. **Availability of alternatives**

No suitable substitutes are available that combine the required properties (high dielectric constant, high energy storage capability, low leakage, and low loss at high current, frequency, and temperatures. To date, no roadmap to substitution or elimination of lead in high voltage ceramic capacitors is provided.

The applicant explains that initial efforts of industry accomplished the substitution of approximately 99% lead in dielectric ceramic high voltage capacitors after the adoption of the RoHS Directive in 2003. Ever since, the remaining uses of lead-containing ceramic high voltage capacitors remained largely unchanged because industry has not been able to find lead-free substitute materials that provide the same combination of desired properties. Thus, no further efforts have been made to phase-out lead-containing ceramic high voltage capacitors from EEE products despite industry having continued to monitor publicly available scientific literature that address possible substitute candidates. The applicant also asserts that industry-run substitution research has continued with no viable results. Evidence of unsuccessful search for technical alternatives cannot be published because of the competitive disadvantage of such disclosure. The exemption request illustrates the industries` unsuccessful efforts in lead-free substitution research by means of illustrative cases:

- Addition of zirconium to ceramics consisting of strontium titanate or barium titanate: the dielectric constant decreased so that the resulting capacitance was less than one-tenth that of the leaded capacitors. ZrSrTi or ZrBaTi based capacitors would therefore require a tenfold larger package volume.

- Strontium titanate has been investigated as a potential lead-free dielectric ceramics substitute, since it has small energy loss and no electrostriction. However, the capacitance is less than one tenth that of lead-added barium titanate. Attempts to use strontium titanate for the design of high-voltage capacitors failed to provide the desired capacitance at small size required for applications in power supplies for household and industrial electrical equipment. The power output of the attached AC adapters becomes unstable and can cause the EEE to malfunction.

- Technical redesign of EEE towards the usage of lead-free high-voltage capacitors: The consequences would be increased product size and weight due to the necessity to size up not only the capacitors but also circuit boards, cooling mechanisms etc. This would contradict the overarching trend towards device miniaturisation in the EEE sector.

Upon request, the applicant offers to provide further detail on the above-mentioned cases as confidential information.

1.4.2. Environmental and health arguments

The exemption request suggests that the use of lead-containing high voltage capacitors helps lowering the resource and energy consumption throughout the lifecycle of an EEE product.

- Leaded dielectric ceramics can be sintered even at lower temperatures than lead-free alternatives (1000°C instead of 1300°C). This reduces the energy consumption for production and allows for a reduced carbon footprint. The exemption request specifies the energy saving potential with 1 MWh per million components produced (in total 220 MWh for all components placed on the EU market per year)
- The reduced the size and thickness of leaded high voltage capacitors saves the use of resources in comparison to the production of larger sized lead-fee components. The miniaturisation also helps to design smaller printed wiring boards and housings, which contributes to material savings.
- The separate collection and recycling of discrete ceramic high voltage capacitors is considered unfeasible because these components are closely incorporated in WEEE. There is no practical way to identify and recover capacitors exclusively during the end of life treatment of WEEE.

1.4.3. Socioeconomic impacts

No detailed socioeconomic assessment is provided, however the applicant refers to the rule of diminishing return on investment, explaining that "*the efforts still necessary in order to substitute all devices incorporating lead in the scope of 7(c)-II will be many times what has already been spent in materials research*."

2. Clarification Questions

1. Please provide the confidential information about unsuccessful attempts to find lead-free substitutes to the consultants for review.

   Answer by UP Exemption #7c-II WG Participants:
   Companies that have confidential information are currently preparing their replies for submission. Replies will be ready by February 7th. Companies will send their inputs directly to Oeko Institute.

2. Are there more concrete data available regarding the trend in application of leaded high voltage capacitors in EEE that is placed on the market in the EU. Are there EU specific consumption data available other than through economic allocation via the GDP?

   Answer by UP Exemption #7c-II WG Participants:
   Most of the lead-containing high-voltage capacitors are produced outside the EU, and many of them are incorporated into EEE outside the EU. For this reason, EU-specific consumption data is difficult to calculate.

3. Can you describe the reasons for the declining use of leaded capacitors since 2013.

   ~~a.~~ Is this a result of substitution in certain areas or shift to other technologies? Please specify such areas.

Answer by UP Exemption #7c-II WG Participants:
To reduce the power consumption, size, thickness and cost of EEE, the industry is promoting the reduction of the operating voltage of mounted devices and the integration of high-voltage devices. As a result, we estimated that the number of high-voltage devices incorporated into EEE decreased, and the number of lead-containing high-voltage capacitors proportionally decreased.
This is due to technical trends in EEE design, and lead-containing high-voltage capacitors have not been replaced in certain areas or applications.

b. What is the reason to believe that the trend observed in the past to reduce the use of lead-containing high-voltage capacitors in EEE has now come to an end, i.e. that the scope of the exemption cannot be specified so that it applies to a narrower group of applications?

Answer by UP Exemption #7c-II WG Participants:
As described in our application, industry is striving to develop alternative technologies. However, at the present stage, we have not been able to develop practical technologies that can replace specific areas and applications. In addition, for instance the application of lead containing high voltage capacitors in power supplies and inverters in high voltage energy systems is getting more and more important. Thus, a further reduction of the amount of lead is not expected from today's perspective.

4. Can you please elaborate for which high temperature applications the use of leaded high voltage capacitors remains essential? Why are such high temperature applications (i.e. >130°C) relevant across all EEE categories, including toys, leisure and sports equipment or automatic dispensers?

Answer by UP Exemption #7c-II WG Participants:
Here, high temperature applications refer to the temperatures that the component must withstand inside the equipment housing.
When an electric current flows through a conductor Joule heat is generated.
If heat dissipation does not occur, the interior of the EEE housing will inevitably reach high temperatures.
The rated temperature of the high-voltage device inside the EEE housing is generally between 60 ° C and 100 ° C, but since the amount of heat generated increases in case an abnormality occurs, the designer must use components that can withstand temperatures from 1.5 to 2 times that of the rated temperature. Therefore, components that can withstand a high temperature environment of 130 ° C or higher are required. This is common for all categories of EEE.
High voltage capacitors have to fulfil the safety requirements related to the EEE where they are incorporated even in case of fault condition, e.g. short circuit or overheating. Thus, high temperature performance is essential for electrical safety of the EEE.

5. What technical options have been explored to design EEE in such ways to avoid the build-up of high temperatures (i.e. >130°C) in the proximity of high voltage

capacitors (e.g. passive cooling or distancing to active components)?

Answer by UP Exemption #7c-II WG Participants:

Four representative technical options are listed as follows:

(1) Reduction of the operating current/voltage of the device.

- Joule heat decreases, and operating temperature is lowered.

(2) Increase of the distance between electronic components heated to high temperatures and the other electronic components.

- This option may not be applicable since it may have an adverse effect on control in analog circuits.

- It may not be applicable to heat-generating parts themselves either.

(3) Addition of heat sinks and heat dissipation sheets to components and boards. (Passive cooling)

(4) Wind blowing with a blower or fan. (Forced cooling).

In case parts of your contribution are confidential, please provide your contribution in two versions (public /confidential). Please also note, however, that requested exemptions cannot be granted based on confidential information!

Finally, please do not forget to provide your contact details (Name, Organisation, e-mail and phone number) so that Oeko-Institut can contact you in case there are questions concerning your contribution.

3. References

Gensch, Carl-Otto; Baron, Yifaat; Blepp, Markus; Moch, Katja; Moritz, Susanne (2016): Study to assess renewal requests for 29 RoHS 2 Annex III exemptions [no. 1(a to e - lighting purpose), no. 1(f - special purpose), no. 2(a), no. 2(b)(3), no. 2(b)(4), no. 3, no. 4(a), no. 4(b), no. 4(c), no. 4(e), no. 4(f), no. 5(b), no. 6(a), no. 6(b), no. 6(c), no. 7(a), no. 7(c) - I, no. 7(c) - II, no. 7(c) - IV, no. 8(b), no. 9, no. 15, no. 18b, no. 21, no. 24, no. 29, no. 32, no. 34, no. 37] - Pack 9. http://rohs.exemptions.oeko.info/. With contributions by O. Deubzer und A. Gibbs.

Murata Electronics Europe B.V (2019): Application for renewal of exemption 7(c)-II of Annex III, Directive 2011/65.