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Environmental Issues In Power Electronics (Lead Free)

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Abstract- **The environmental impact of lead released from electronic equipment, other than batteries, may seem to be extremely low but it is becoming a major concern all over the world. Japanese and European manufacturers are already working to remove lead from all new products before such action becomes mandatory by law. Because of the massive use of DC/DC converters within new electronics applications, 'lead-free' is considered to be a major concern for next generation of systems**.

I. Introduction

There has been a long series of debates around lead and other undesirable substances since the Framework of "The United Nation Convention On Climate Change" [1] was adopted on May 1992. That Framework was signed at the Convention of Rio de Janeiro in June 1992 and was adopted at the third session of the Conference of the Parties to the UNFCCC in Kyoto, December 1997 [2].

The lead contained within the power electronics industry is an insignificant factor with respect to what the United Nations Convention on Climate Change aims to achieve. However, despite the weight of arguments against the decision to ban lead from passive and active components, the electronics industry has started to move towards reducing the use of hazardous substances and to implement global recycling policies, before local or global regulations come in force.

This paper explores 10 years of history, and the impact of environmental issues on the power supply industry.

II. Environmental

A. General Environmental

As a starting point, it is important to understand under what circumstances the lead within electronic components could impact the environment. Protecting the environment represents one of the greatest challenges facing society and as yet we have limited understanding the enormous complexity and interdependence of the organisms that make up the world's many ecosystems.

And as if that were not enough, every day brings to light new environmental problems or incidents that can be attributed, either directly or indirectly, to human activities. These problems/incidents usually fall into one of three categories.

The first category creates environmental impact on a global basis. For example, diminishment of the stratospheric ozone layer caused by the use of chlorinated or brominated, low molecular weight hydrocarbons; or global warming, the result of extensive use of fossil fuels.

The second category involves problems that have a regional impact on the environment. For example:

- Acid rain in the southern parts of Scandinavia and in the northeastern parts of the US.
- A high concentration of ground-level ozone-forming compounds that diminish crop yields, due to discharges of nitrogen oxides and hydrocarbons (mainly from the transportation industry).

The third category includes problems that have a local impact on the environment. Very often, these relate to the unwanted presence of "dirty" industries or landfill areas which, being perceived as polluters of air, water or land with negative impact upon the environment.

That third category is directly addressed by the European Community text ratified in June 2001, the WEEE [3].

The environmental debate is heavily laden with major problems. On the one hand, we know too little about too many issues to be able to piece together a holistic view of the environment. For example, we can only guess at the outcome of global warming.

After ten years of extensive research, which involved thousands of researchers, the International Panel on Climate Change (IPCC) concluded that we are already living in an era of global warming. They also noted the potential for collateral damage from lead released from electronic components due to poor End-Of-Life management of products [4].

B. Why remove lead and lead compounds?
Lead and lead compounds are of particular concern because of their toxicity in children. Children and developing fetuses are known to absorb lead more readily than adults, and, once in the body, lead is distributed into blood, soft tissue, and bone. Children exposed to lead can suffer from brain damage, central nervous system damage, slow growth, hyperactivity, and behavior and learning problems. Adults exposed to lead can suffer difficulties during pregnancy, high blood pressure, nervous disorders, and memory and concentration problems [5].

II. Worldwide overview

With respect to environmental protection, the U.S.A., Japan and Europe have developed different initiatives to reduce and limit the uses of hazardous chemicals. Some of these initiatives started before the United Nations adopted the framework convention on Climate Change.

A. United States of America

1) Reid Bill and EPA:
In early 1990, the Senate resumed consideration of the bill entitled "Lead Exposure Reduction Act of 1993" (Senate – May 25, 1994) [6]. The bill, subsequently called the "Reid Bill" after Senator Reid, who worked hard to protect the environment and future generations against irreversible damage from lead exposure.

The Reid Bill proposed restricting the use of lead as follows:

"The manufacture, importation or processing of paint, toys and recreational game pieces, plumbing solder and fixtures, and ink that exceeds certain levels of lead content deemed to be unsafe will be prohibited; these new standards will be phased in for various specified products.

The Environmental Protection Agency (EPA) will inventory all lead-containing products used in commerce, make a list of those products in that inventory that it thinks may present an unreasonable risk of injury to human health or the environment. The Environmental Protection Agency (EPA) shall require the labeling of products on that list according to their lead content, all lead acid batteries will have to be recycled."

In September 2001, The United States Environmental Protection Agency took a major step by issuing [7]:

"Emergency Planning and Community Right-to-Know Act-Section 313: Draft Guidance for Reporting Releases and Other Waste Management Activities of Toxic Chemicals: Lead and Lead Compounds."

This document is intended to provide guidance on the specific details of this new regulation, which facilities must file release reports for lead and lead compounds, and methods to estimate releases of lead, and lead compounds into the environment following manufacture, processing, use, or waste management activities of lead and lead compounds.

The original Reid Bill hasn't yet been implemented in electronics equipment, other than in lead acid batteries commonly used in UPS systems as energy backup. The Draft Guidance released by the NPA is a major move to strengthen lead-free initiatives.

In January 2001 the EPA lowered the reporting threshold for lead under the Toxic Release Inventory (TRI) rule to 100 lbs. (approx. 285 lbs., eutectic solder). The new rule is effective immediately and the requirements for lead and lead compound emissions applied to all lead use and waste management in 2001 [8].

2) NGO Initiatives:
In the late 1990s, non-governmental associations started to develop lead-free initiatives to investigate different scenarios as lead-free regulations are put into place in different parts of the world.

One of those, The National Electronics Manufacturing Initiative (NEMI) leads a task group, working in close cooperation with major manufacturers, to support lead-free manufacturing initiatives. In conjunction with major CEMs, The National Electronics Manufacturing Initiative adopted a pro-active approach by initiating a lead-free committee [9].

Others American NGOs are also working on lead-free initiatives, e.g. The Institute for Printed Circuits (IPC) and the International Tin Research Institute [10].

At of today, there are no specific regulations in the U.S.A. banning lead in electronic components but, as previously mentioned, several initiatives are underway to get products and processes ready to meet European, Japanese and future US market requirements.

B. Japan

The Japanese electronics industry has always been very environmentally conscious. In 1997, more than 700 organizations were certified to ISO 14001 and two-thirds of all certifications were related to electronics companies. In general, Japanese industries are always preparing themselves for any future environmental contingency. Lead-free initiatives started long before any industry regulation was introduced.

In the early 1990s the Japanese community started to implement control of the lead released out of landfills and waste disposal.

In 1991 "The Waste Disposal Law" required disposal within the facility when the detected lead amount is over 0.3 mg/L, measured by an eluting test of industrial waste.

In 1994, "The Water Pollution Prevention Law" lowered the permitted lead content of rivers from 0.1 mg/L to 0.01 mg/L.

In 2001, "The Consumer Electronics Recycling Law" required manufacturers to recovers harmful material.

Beside the legislation, Japanese manufacturers took the lead-free challenge as a marketing opportunity to increase market shares when regulation will ban lead from electronic equipment.

As in the U.S.A., NGO are developing initiative and a lead-free development group is supporting Japanese manufacturers. The Japan Electronics and Information Technology Industries Association (JEITA) [11] supports lead-free investigations and consolidates independent test results.

Strong manufacturing initiatives and an objective to use Pb free solder in mass production, starting in 2001, combined with strong NGO support, gives significant leadership to Japanese manufacturers. Several of them have already released lead-free components and end-user products made without the introduction of lead during manufacturing (lead-free solder, low lead components…).

During 2001, most CEMs and in-house manufacturing plants migrated from SnPb to lead-free solders (e.g. SnAg or SnAgCu). The 2001 implementation of lead-free processes in manufacturing by the Japanese electronics industry is the first step before the next milestone of 2003. Japanese lead-free initiative fixed three milestones to gradually remove lead from all components and sub-assemblies.

From2003, lead-free solder should be used preferentially.

From 2005 to 2010 solder containing Pb should only be used by exception.

By 2015 the use of Pb in solder should be eliminated.

Compared to European regulation to eliminate lead after 31st of December 2006, the Japanese roadmap seems to be well behind the WEEE [3]. This is because the European ban on lead is very aggressive, both in terms of its timeline and scope. The European schedule requires elimination of lead by end of 2006 (effective 1st of January 2007). Despite regulation, for technical reasons, some exemptions might be required to ensure both product availability and reliability.

C. Europe

On the 7th of June 2001, the European Council reached unanimous political agreement with respect to adopting a common position on the proposals for the Directive on Treatment of Waste from Electrical and Electronic Equipment (WEEE) [3] and the Directive on the Limitation of Hazardous Substances in Electrical and Electronic Equipment (ROHS) [3]. The Council agreed that:

1) WEEE (Waste of Electrical & Electronic Equipment)

- Collection systems are to be set up 30 months after the entry into force of the proposed Directive, allowing final holders and distributors of equipment to return WEEE free of charge.

- When supplying a new product, distributors shall be responsible for ensuring that such waste can be returned to the distributor at least free of charge on a one to one basis as long as the equipment is of equivalent type and has fulfilled the same functions as the supplied equipment.

- Member States may, for a period not exceeding 5 years after the entry into force of the Directive, set up or facilitate alternative free take-back systems.

- Member States may allow producers to set up and operate individual and/or collective take-back systems.

- The collection target for private households should be set at a minimum rate of 4 kilograms on average per inhabitant per year and is to be reached within 36 months from the entry into force of the Directive.

- Recovery and recycling targets are to be reached within 46 months of the entry into force of the Directive.

- For large household appliances, the rate of recovery shall be increased to 80%, the rate for re-use and recycling to 75%. For IT, telecommunication and consumer equipment, the rate of recovery is 75% and the rate for re-use and recycling 65%.

  For the other categories the rate of recovery shall be 70% and the rate of re-use and recycling 50%.

- Producers will pay for the collection, treatment, recovery, and environmentally sound disposal of WEEE from private households. The financing shall be provided by means of collective and/or individual systems.

- The responsibility for the financing of the costs of "historical waste" shall be provided by one or more systems to which all producers present in the market when the respective costs occur contribute proportionately.

- The setting up of the financing systems should be reached within 30 months from the entry into force of the Directive.

  An exemption from the financing requirements was granted to small independent manufacturers with fewer than 10 employees and a turnover of less than 2 MEUROS for a transitional period of 5 years after the entry into force of the Directive.

2) ROHS
The purpose of this Directive is to approximate the laws of the Member States on the restrictions of the use of those hazardous substances in electrical and electronic equipment which cause significant environmental problems during the waste management phase and to substitute them by a certain date.

The Council agreed that by 1 January 2007 at the latest, **Member States shall ensure that new electrical and electronic equipment put on the market does not contain lead**, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and/or polybrominated diphenyl ether (PBDE).

Any amendments which are necessary in order to adapt the Annex to this Directive, referring to the exemptions for phase-out granted for applications of such substances where e.g. substitution is not feasible or would outweigh the environmental benefits, are adopted in accordance with the comitology procedure. This adaptation is to be based on scientific and technical progress and shall be carried out at regular intervals.

3) NGO initiatives:
In a move aimed at accelerating the use of lead-free packages and stimulating the further development of lead-free technologies, three major European semiconductors manufacturers unveiled their proposal for the world's first standard for defining and evaluating lead-free semiconductor devices.

Starting in February 2001, the three companies have developed the proposed standard, which provides a common definition of lead-free and assesses factors such as solderability and reliability of alternative materials.

One of the major barriers against eliminating the use of lead in the industry has been a lack of internationally agreed standards and methodologies for evaluating the quality and reliability of 'lead-free' technologies. In contrast, single lead-tin alloy has been used for many decades and standard procedures are used worldwide to evaluate its quality and long-term reliability.

To accelerate the transition to lead-free technology, the electronics industry needs a common approach to quantifying solderability, heat resistance and other issues that affect reliability. At present, there is not even an internationally agreed definition of the maximum amount of lead that can be allowed in a 'lead-free' component or process.

The three companies will be able to introduce their lead-free products far in advance of the legislative deadlines (January 1st 2007). The proposal of the three manufacturers contains an upper limit for lead-free components of 0.1 percent related to individual materials, not whole packages or components.

III. Impact on Power Electronics

Lead-free regulations and pending regulations will have a major impact on power electronics, from single components (e.g. diode, connectors, control ICs, transformers…) to final products e.g. DC/DC converters.

Moving from SnPb soldering to lead-free soldering means an average peak temperature increase of 25 °C from 235 °C for SnPb to 260°C for SnAg or SnAgCu..

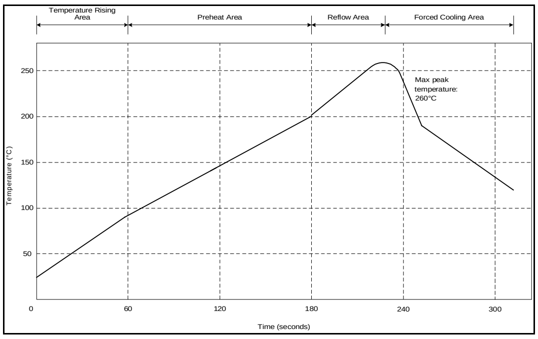
There is also a requirement to eliminate SnPb from leadframe plating and to substitute another alloy, possibly more expensive, plating.

For hybrid surface mountable DC/DC converters using ceramic substrates the transition should be easier than for converters based on traditional printed circuit board technologies. A high percentage of DC/DC converters based on ceramics substrates are already using SnAg solder. The main challenge for this category of products is to remove lead from lead frames and terminations.

Besides differences in substrate or PCB technology, implementation practices for lead-free manufacturing will also differ between traditional through hole and surface mount converters.

Through holes products are often wave soldered and the effect of an increase of soldering temperature by 25 °C will have little impact on products.

It is a different scenario for surface mount products. These will be exposed to 260 °C peak and an average of 255 °C + 5% for a duration of 10 seconds.



Lead-free solder generic soldering profile

Surface mount products should be designed in order to stand second reflow and higher temperatures, reducing the size of plastic encapsulated components to limit the risk of the so-called ‘pop-corn effect’ caused by moisture absorption.

In terms of design, industrial, lead-free compliant surface mount converters are getting closer to military converters. Choice of components is not only based on electrical performance/lead content but also on their ability to withstand higher temperatures.

Several companies have decided to go ahead with an Sn-Ag-Cu compound, which may necessitate replacing old equipment used for reflow soldering (4 to 6 zones). This is because the increase in dross generated, compared to using conventional Sn-Pb processes, requires inert gases, such as N_2, to be purged. Equipment replacement is also necessary because old reflow tunnels cannot provide safe and stable manufacturing conditions at the higher temperatures encountered in lead-free soldering (6 to 11 zones).

This represents a significant investment problem for manufacturers using standard infrared soldering equipment and having to replace reflow tunnels to ensure compatibility with nitrogen gases and new peripheral equipment.

IV Conclusion

Considered just a few years ago as a fad, lead-free initiatives in Japan, Europe and the U.S.A. have demonstrated just how seriously the electronics industry takes the issues. New regulations or pending regulations will increase pressure on manufacturers to release lead-free components, sub-assemblies and final products in future years. The answer to the question “should power electronics be lead-free” is certainly YES. There is no doubt that will become a standard market requirement.

Acknowledgment

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