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Design for Low-Halogen Green Electronics

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Abstract
Green Design has recently gained significant interest in the electronics industry all over the world and will remain one of the hottest topics for the upcoming years. Besides reduction of consumed energy, Original Equipment Manufacturers (OEMs) are increasingly restricting the use of certain halogens as flame retardant substances in plastics. For some low- to mid-temperature thermoplastics, halogen-free solutions of comparable performance are commercially available. However, for certain high-temperature plastics, which are typically used in connectors and sockets, there may be no drop-in solution that meets the engineering and cost targets. Further, these new materials require re-qualification of connectors and typically need new capital expenditures for mold tooling to account for changes in processing and shrinkage. In certain areas OEMs and connector manufacturers may face a significant impact on processing or electrical and mechanical performance as well as on the total system cost. In this paper we review the current industry status with respect to the introduction of halogen-free plastics and will discuss various options to implement Green Design solutions. These alternatives allow a significant reduction or elimination of halogens without jeopardizing product performance, safety or cost; in some cases, the material similarity will reduce connector re-qualification or retooling costs. The concept of Green Design is derived from the IEC62368 standard, which is currently being discussed as a global standard within the electronics industry covering audio/video and IT-equipment.

Introduction
Materials used for enclosures, structural parts and insulators used in Electronics need to comply with Underwriter Laboratory (UL94) flame retardance tests and fulfill certain self extinguishing characteristics defined as V-0, V-1, V-2, HB.

Original Equipment Manufacturers (OEM) and connector manufacturers for many years have been specifying plastic materials, to conform to meet the UL94-V0 flammability standard for plastics, for connectors and sockets. This generic specification enabled the use of identical connectors and sockets in any application and no further differentiation needed to be accounted for. It also gave the connector designer a higher safety margin on his design. This was an easy approach to implement, however it introduced over specification for many of these applications.

Certain polymers such as Liquid Crystal polymer (LCPs) are intrinsically flame retardant, at least if the thickness is not thinner than 0.2mm. Other polymers such as polyamides or polyesters are intrinsically not fire resistant. The choice of the right polymer is driven to a large extent by the performance requirements of the various connectors and sockets. Polyamide electrical isolation, which is commonly used in connector & socket housings, require flame retardants to achieve high flammability ratings requested by OEMs.

To make polyesters and polyamides flame retardant, brominated flame retardants (BFRs) are commonly used. Polyvinyl Chloride (PVC) is used for many cables and wires with chlorine acting as an efficient flame retardant.

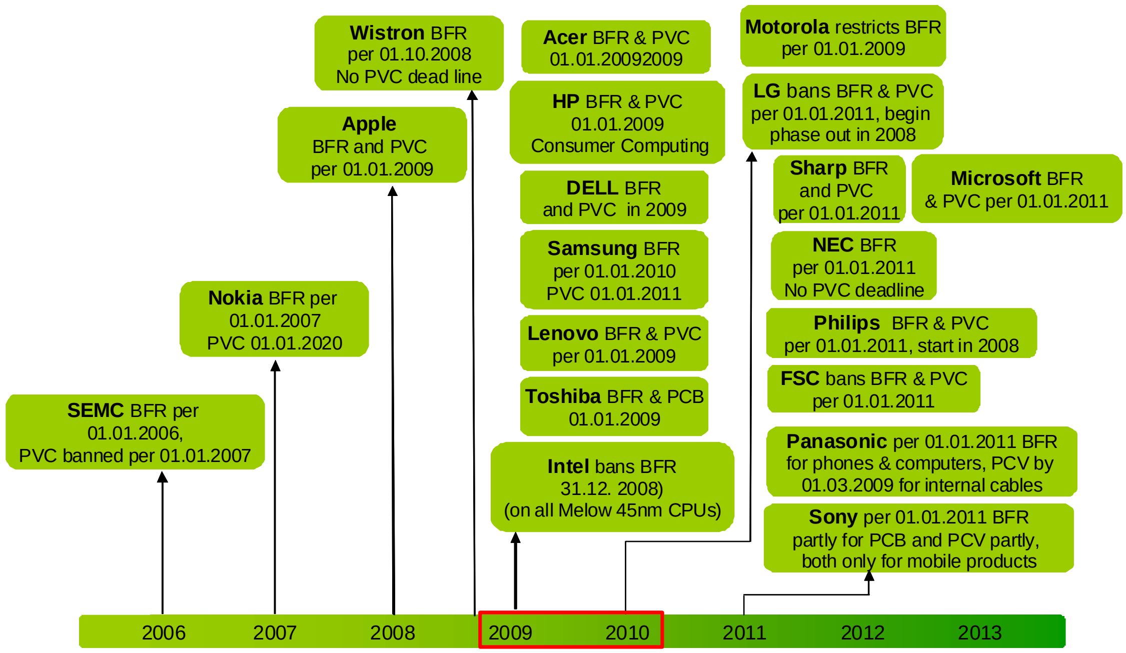

Figure 1: OEMs/ODMs halogen-free roadmaps showing the major transition around 2009/2010.

Figure 1 gives a summary of OEM/ODM transition roadmaps towards halogen-free plastics, by banning the use of BFRs and PVC. The three remaining halogens Astatine, Fluorine and Iodine are not included in the move towards halogen-free plastics. Reason is their significantly less occurrence as well as lower potential risk for hazardous impact under certain conditions. BFRs and PVC are non critical in daily use by the end customer and show very effective flame retardant (FR) activity. They also have good performance-safety balance. However, the inappropriate incineration (<800°C) in the end of life cycle of electronics equipments has led to a growing concern that these materials may have risks to health and the environment. As a result, a number of OEMs as a part of their environment initiatives are setting deadlines to ban the use of plastics containing halogens. These transitions will peak around 2009/2010, requesting now for proper halogen-free solutions to work on the new designs.

The move to halogen-free plastics is not easy. In significance it is similar to the move earlier, by the electronics industry to go lead free, but with much shorter implementation time. This brings challenges in supply chain and secondly, the reliability of halogen-free flame retardants is not tested on a long term. Further, a halogen-free high temperature plastic cannot be a drop in replacement for the existing plastic with halogenated flame retardant. These need to be clearly thought of, together with the mechanical properties, flow, and cost compromises to meet the design and environmental needs.

Plastics suppliers such as ourselves are active to address the situation. We are the market leader in high heat resistance resins with a market share of >30% in high temperature polyamides and a track record of over 15 years in the use of halogen-free polyamides in the Electronics' industry. With its direct involvement and membership at the International Electro technical Commission (IEC), we are equipped well to provide the best material. To provide the best total solution, we are partnering up with leading connector manufacturers such as the world's largest connector manufacturer with >500.000 unique part numbers/year and a broad market coverage.

Such close co-operation enables solid knowledge of the flammability requirements for various applications. When engineering an electronics device for fire retardancy, a key engineering parameter is the source of flame. Without an ignition source, flammability is not an issue. Ignition sources have two fundamental categories: internal and external. An external source is an unrelated flame such as would be found when a device comes into contact with a candle. The flame from the candle can ignite the exterior of an electronics device if it comes into contact. The other source of ignition is internal to the device and relates to power sources. The International Electro technical Committee (IEC) has proposed a standard, IEC 62368, to define these sources and the required flammability requirements.

This new standard lays down design considerations of new electronics to enable them to be environmentally safe. Based on this, possible applications can be identified which do not necessarily require the highest UL94-V0 or V1 flammability rating, but which can tolerate a UL94-V2 or HB rating.

UL94HB[1]:
The UL94HB, or horizontal burn, test method uses a 0.83 to 3 mm thick polymer bar which is at least 100mm long. A flame is applied to the end of the bar for 30 seconds. To achieve an HB rating, the materials must cease to combust before reaching the 100mm mark with an average burn rate of 75mm per minute or less. The material can be rated as HB to a thickness down to 0.83mm. An HB rating or better is readily achievable for many plastics. UL recognizes 35,398 grades of polymers with an HB rating or better and 15,789 grades with a rating of HB. This test is similar, although slightly more stringent, to the FMVSS 302 which governs the use of materials in the automobile passenger compartment. The primary criterion is a slow flame spread that would allow the user to detect and either stop or remove themselves from the situation.

UL94V[2]:
UL94V is a more stringent flammability test than the UL94HB test. The UL94V test method uses bars of different thickness to determine the flammability rating of the bar at thickness. A 15mm long, 13 mm wide polymer bar with the desired test thickness is oriented vertically above a Bunsen burner with a layer of surgical cotton placed 300 mm below the test sample. First, the bottom of the test sample is ignited by applying a flame with the Bunsen burner for a 10 second dwell time after which the flame is removed. The combustion time duration is recorded. For either the V0 or V1 rating, any flaming droplets must not ignite the surgical cotton. The flame is applied at a set rate and angle for a maximum of 2 applications per bar. The flammability score depends upon the performance metrics listed in the table below.

The test can be repeated at varying thicknesses to determine the minimum thickness for which a V-0 rating can be obtained. This vertical burn test has three performance categories. V-0 is the most severe requirement, while V2 is the least severe. Flaming drips is one of the key differences between the V-0 and V2 rating. V1 falls between these two performance ratings and allows a longer combustion time compared to V-0. The differences between V1 and V-0 are fairly small and it is rare that engineering polymers of interest to the connector industry are engineered to a performance ranking of V1. The most significant difference between the V ranking and HB ranking is that V rated materials must self extinguish.

Table 1: Table of UL94 Flame Ratings

	94V-0	94V1	94V2
Total combustion time in seconds for 10 flame applications	50	250	250
Maximum time for any individual flame occurrence	10	30	30
Glowing combustion time in seconds	30	60	60
Cotton indicator ignited by flaming particles or drops	Not allowed	Not allowed	Allowed but cannot ignite cotton more than briefly.

Passing the UL 94V test with a V-0 rating requires efficient flame retardant performance, either from an inherently flame retardant material or from an additive package. Getting a V-0 rating at a small thickness is even more challenging. Some materials have excellent flammability characteristics until the thickness is reduced below a critical level. Thinner samples are more likely to drip and have greater surface area to encourage combustion after the removal of the flame.

UL94 5V[2]:
The UL94 5VA of 5VB test classifications are similar in test method to UL94 V-0, but the acceptability requirements are more severe. Materials classified as 5VA or 5VB must also pass UL94 V-0, V-1 and V-2. The test method is similar to UL94 except for the flame application. The flame is applied at an angle of 20 degrees for 5 seconds, then removed for 5 seconds.

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1 Search results from the Underwriters Laboratory (UL) website at http://iq.ul.com using a search on flammability rating of HB or better.

2 UL 94, Test for Flammability of Plastic Materials for Parts in Devices and Appliances, Underwriters Laboratories, 29JAN01, ISBN 0-7629-0082-2.

The cycle is repeated until the flame has been applied 5 times. After the fifth flame application, the after flame time, afterglow time and indications of flaming drips are recorded. Table 2 indicated the flammability classification ratings for the 5V test.

Table 2: Material classification ratings for UL94 5V tests

Criteria	UL94 5VA	UL94 5VB
After flame time and afterglow time after 5th flame application	<= 60 seconds	<= 60 seconds
Cotton ignited by flaming particles or drops	No	No
Burn through of any plaque specimen	No	Yes

Our companies are jointly supporting the electronics industry to find the right flammability rating for different applications and as such, avoid the use of flame retardants to some extend in low power applications. In certain applications of higher power, a higher flammability rating is required.

Figure 2 shows the two possible paths which are proposed in this paper. The underlying rational will be outlined later in the text under the IEC62368 chapter. The path depicted on the left side of Figure 2 as UL94-V0/V1 is suggested for applications with a power higher than 15W. For such applications, the IEC standard recommends a V1 or V0 flammability rating. This approach has the advantage that OEMs/ODMs can continue to specify as previously. However, it poses significant challenges to polymer and connector suppliers and will lead to higher cost across the value chain. Typical examples of such applications are connectors and sockets with individually higher powers such as the power socket or CPU sockets.

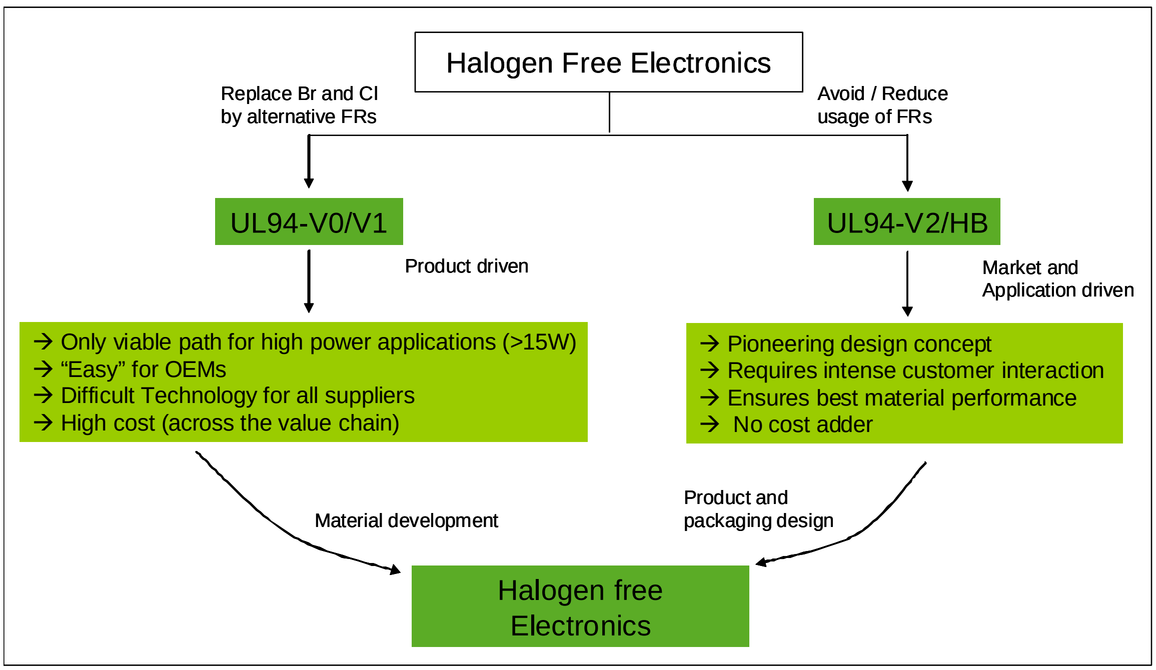

Figure 2: Our approach to address possible routes towards halogen-free Electronics

The path depicted on the right side of Figure 2 as UL94-V2/HB suggest the use of V2 or HB graded polymers for applications with a power less the 15W. The pioneering approach, if followed consequently, will result in the lowest cost for the value chain, provide a higher mechanical performance for sockets and connectors and will remove ~10-20 weight percent of flame retardants per kilograms of polymer used. However, the approach requires intense cooperation across the value chain and some specific training to classify the right applications in use.

The principle as shown in Figure 2 is also known as Green Design. This is a viable path towards a fast and cost effective move towards low halogen Electronics which are safe and pose no threat to the environment. Since connectors and sockets are the biggest areas of concern, this paper will primarily focus on Green Design of these components.

To provide OEMs/ODMs with the best possible solution, we offer our entire range of polymers in halogen-free grades. To support existing designs and customers with different halogen-free conversion timelines, we continue in parallel to also offer existing halogenated grades. The OEM/ODM decides which material is selected.

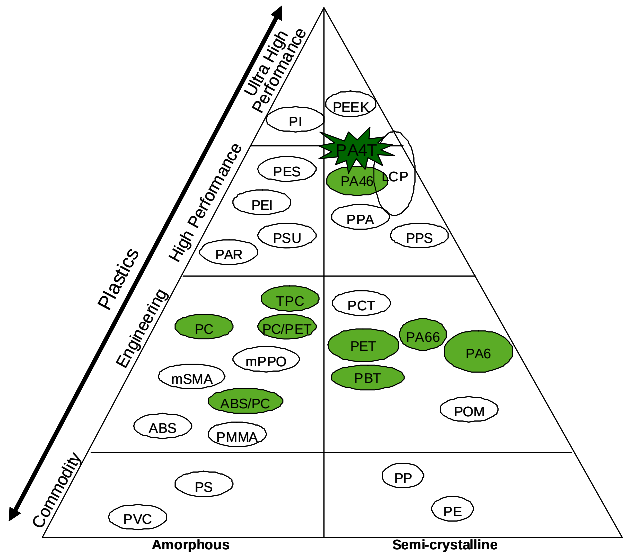

Figure 3: Our halogen-free material portfolio.

In the plastics industry, the most challenging conversions to halogen-free is for PVC replacement by ThermoPlastic Elastomeres (TPE), especially ThermoPlastic Copolyesters (TPC) and for high temperature Polyamides with melting temperatures above ~270°C. There are experiences in the market that for certain halogen-free materials, customers have observed high levels of brittleness, bad smells in the material, blooming or even a significant degree of corrosion to the tool and screw during the processing of these halogen-free materials. We feel that only after significant internal testing new materials will be launched. In this paper, we publicly announce the availability of halogen-free high temperature polyamides with no such issues. An example is our new halogen-free product family that has been successfully tested for applications, where a high flammability rating is required.

Additionally, we have recently announced an entirely new fundamental polymer family characterized by a unique balance of high melting temperature (320°C), an ultra high glass transition temperature Tg (135°C) and the highest stiffness among polyamides. This characteristic, combined with the lowest observed blistering among polyamides, makes this material a viable alternative for applications where lead-free Surface Mount technology (SMT) is used. Our companies have been working intensively together to test and qualify this material and successfully tested it for various applications which have previously required LCPs.

The introduction of an entirely new generic polymer in the chemical industry has become quite a challenge and a unique occasion. Any fundamental developments require substantial investment and long range planning to ensure a safe launch and a viable product. While new polymer family introductions are rare, they are exciting times to consider new possibilities.

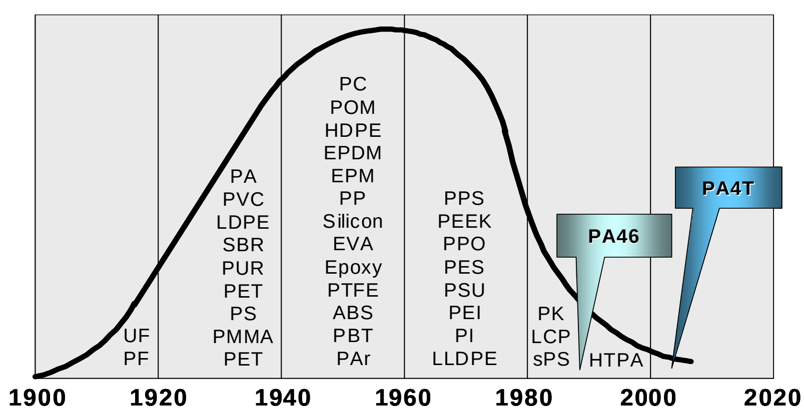

Figure 4: The introduction of new polymers in the chemical industry.

Figure 4 shows many of the new polymers introduced since 1900. The majority of new polymers have been introduced between 1930 and 1970, with a sharp decrease since then. We are the only company to recently introduce two entirely new polymers. Continued commitment to innovation is a key driver for such developments.
Our materials have been engineered as halogen-free polyamides, successfully tested by multiple customers without any issues such as brittleness, outgasing, blooming or corrosion.

Another important material which needs to be available in halogen-free is a high performance PVC replacement. ThermoPlastic Elastomers (TPE) or more specifically ThermoPlastic Copolyesters (TPC) are ideal candidates, since they fully comply with the high requirements of the cable industry such as:

- Halogen-free
- No use of Plasticizers
- Temperature rating of 105 °C
- Excellent Chemical resistance
- UV stability
- High Flexibility
- Color Stability
- Zero re-investment on tooling
- Excellent processing

Halogen-free TPC can be used in application as a viable PVC replacement such as:

- Power cord insulation & jacket
- USB cable Jacket
- Data Cable Jacket
- DC power cable Insulation and Jacket
- Over molding
- PVC replacements

All our TPC solutions pass UL standards and VW-1 testing and comply to UL62, UL758 & tested per UL1581

While the Electronics industry has already since 2006 successfully launched halogen-free applications such as mobile phones, Nokia and SonyEricsson being among the first to completely convert their product portfolio to halogen-free, the PC and Consumer Industry is following only recently with an approx. 2 years time delay. A major difference between these industries is the use of different power levels, making such a conversion easier for the communication industry. Furthermore, the halogen-free PCBs used in these industries are also of different dimensions.

The first larger scale, halogen-free PCBs, are revealing an additional level of complexity in the switch to halogen-free. Halogen-free PCBs are significantly stiffer compared to halogenated PCBs. This result has been intentionally tuned due to the increasing move towards small pitch sizes in Ball Grid Array (BGA) packages and so called Wafer Level Chip Scale Packaging (CSP). The transition from traditional ≥0.5mm pitch sizes to 0.4mm and 0.3mm is only possible if the PCB becomes stiffer and therefore thermal expansion to these semiconductor components becomes acceptable to pass the reflow soldering process.

However, with the first larger size halogen-free PCBs being now assembled, it appears that the CTE mismatch to large form factor sockets is becoming a key issue in assembly. This CTE mismatch leads to significant warpage issues.

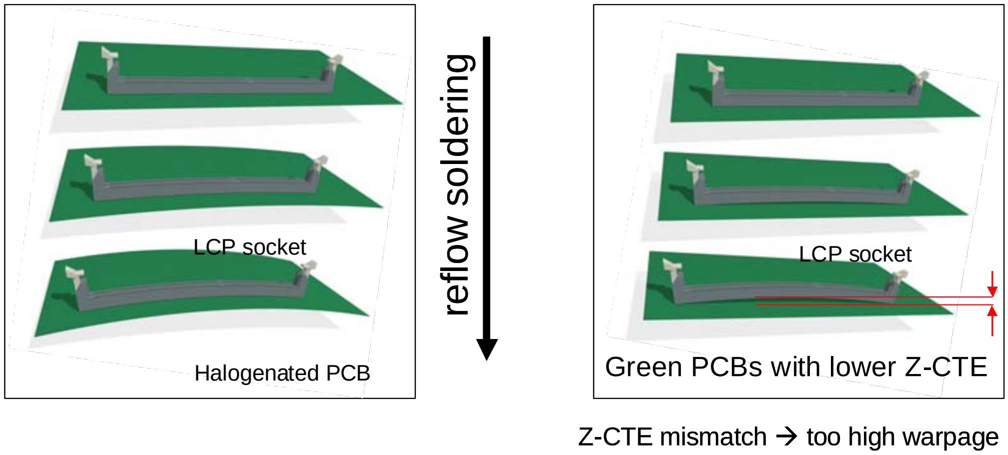

Figure 5: Warpage resulting from CTE mismatch between halogen-free PCBs and long form factor sockets

Figure 5 shows the involved issue. The left side of Figure 5 shows a halogenated PCB with a long form factor socket made of a standard LCP. Both the PCB as well as socket warpage during the reflow process and after cooling the warpage can relax due to the similarity in the magnitude of warpage. On the right side of Figure 5 the same situation is depicted for a stiffer halogen-free PCB with the same standard LCP used for the socket. While the warpage of the socket has remained identical, the warpage of the halogen-free PCB is on average approximately 50% lower as compared to the halogen-containing PCBs. Hence, during the cooling phase after reflow the warpage can not relax entirely and is frozen in the system. For large form factor sockets such as FPC, SODIMM or DDR sockets this warpage is therefore not acceptable anymore and will lead to a significant reduction of line yield at the OEMs/ODMs. Since system cost of entirely assembelled PCBs at this stage is highest, the warpage issue needs to be addressed with high attention and is forcing the connector manufacturer to entirely new designs which can flexibly adjust the heighth of the socket to the PCB. It needs to be mentioned that any such concept will solve the warpage issue to a certain extent, but will simultaneously also introduce additional issues and risk. It is therefore favourable, to have warpage optimized polymers which are fitting to the CTE range of halogen-free PCBs.

Alongside our halogen-free grades, war page optimized grades based on patented technology have been developed which have been specifically tuned to address this warpage issue. The related CTE mismatch is acceptable and warpage criteria for the assembly of the board and the sockets have been successfully passed. The major difference to other warpage optimized materials such low warpage LCPs is the fact, that mechanical strength, notably toughness, of these materials remains high enough to cope with high pin insertion forces and pressure required for DDR. Furthermore, the high weld line strength of these materials allow design optimizations in the number and location of the tool gates so that additional warpage optimization can be achieved by the design. LCPs with their lower weld line strength impose some limitations in the design which also needs to adjust for low weld line strength.

While the above shows that there are solid polyamide solutions with high flammability rating available, we will now focus on options how to reduce the total amount of flame retardants used in electronics. This will be based on the IEC62368 standard.

IEC 62368 standard

Currently IT and Audio/Video equipments follow two different IEC standards, IEC 60950-1 and IEC 60065. The IEC 62368 harmonizes these two standards covering both IT and audio/video applications. OEMs will have 5 years from Jan 2009 to adopt the new standard.

This IEC standard differentiates between various applications and this presents an easier and a quicker workable solution for designers. With this move to the new standard, the IEC is now also covering the probability of an existing, external flame caused e.g. by a candle which can accidentally ignite an electronic application when in close proximity. Figure 6 shows the overview of the new IEC standard.

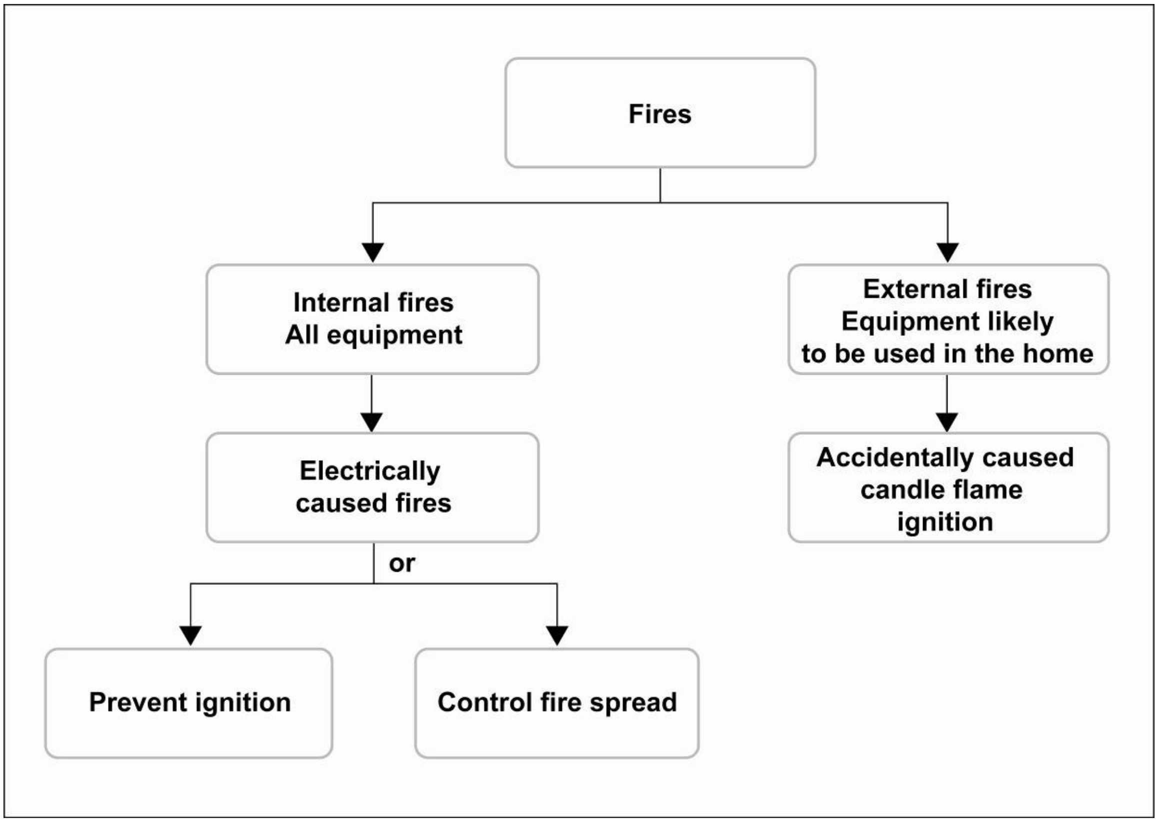

Figure 6: IEC62368 specification deals with fires in electrical applications. Internal as well as external fires are covered

A fire can have two sources: either it is caused internally within electrical equipment by e.g. malfunctioning components or it can be caused externally e.g. by a candle accidentally getting too close or in direct touch with electrical equipment. In case of an internal fire, a designer has two options to take precautionary methods: he can either design the equipment to prevent ignition, or he can design the equipment to avoid the spread of fire.

To summarize the IEC62368 standard, we have differentiated between internal and external connectors and also included some examples to enables a fast transfer to the applications.

Connectors

Ignition as well as spread of an internal fire depends primarily on the power level of the electrical circuit. As shown in Figure 7, depending on the power level there can be three categories, PS1, PS2, and PS3.

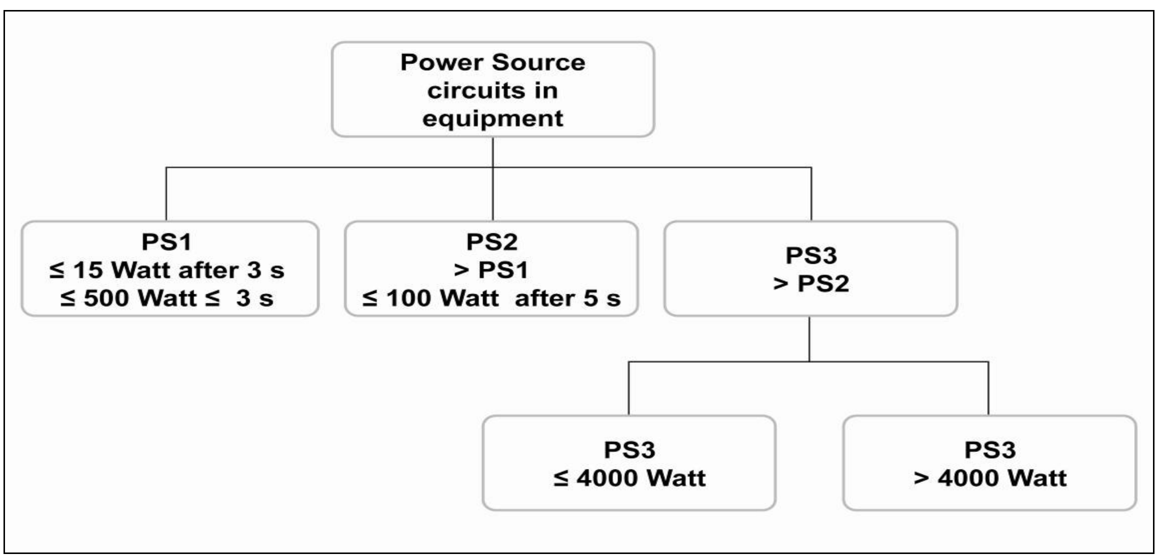

Figure 7: IEC62368 classifies three different power sources PS1, PS2 and PS3.

Figure 8 shows the impact of the power source on ignition.

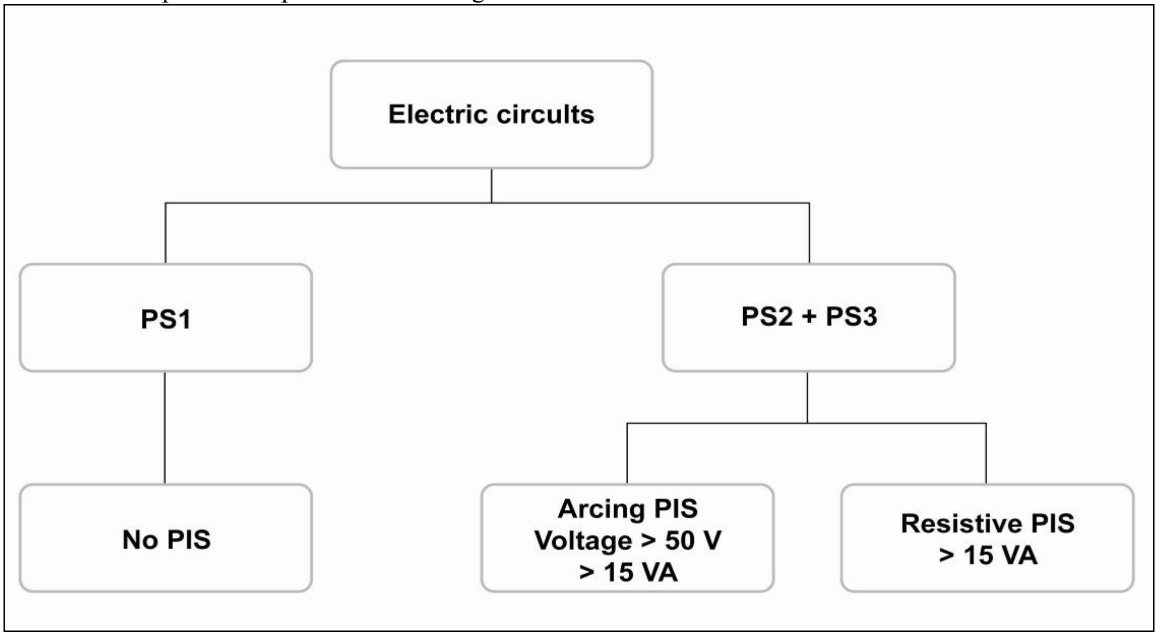

Figure 8: Impact of the power source on ignition.

A PS1 is a non potential ignition source (PIS). The related electrical powers are too low to cause any ignition. In the case of PS2 and PS3, that is not the case, leading to either arcing ignition (*e.g.*, between two connector pins) or resistive ignition (*e.g.*, by an overheating semiconductor component).

This classification and relation between power in a circuit and potential risk of fire is important since it can be a powerful Green Design guideline for engineers at an early step of a new application.

All possible Electronics connectors can be classified into internal and external connectors and will be described through the IEC recommendation on flame retardance. For internal connectors, designers can follow two different choices based on their own preference. They can either follow a "Prevent Ignition" path, or they can follow a "Control Ignition" path, both of which are viable options according to the IEC standard. Only one of them needs to be followed to provide the highest fire safety for electronic equipment.

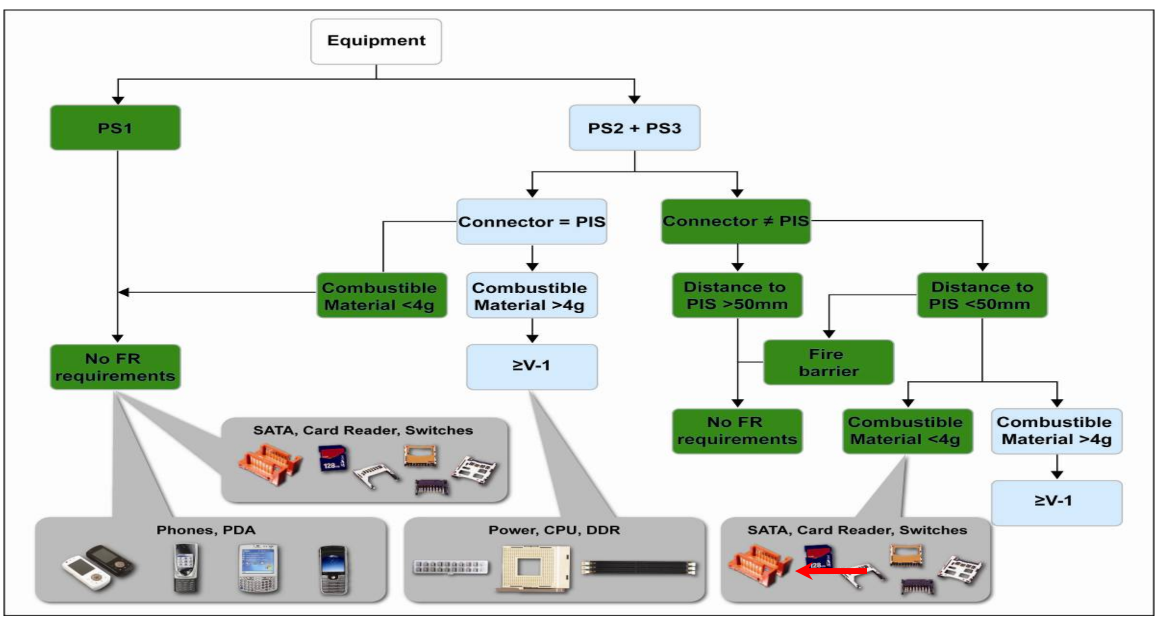

Figure 9: Prevent Ignition, internal connectors. Power level categorization and flame retardance requirements of internal connectors, based on IEC62368 specification to prevent ignition. For illustration some connectors and applications are illustrated.

Let's start with the prevent ignition case: Figure 9 shows how to prevent ignition of internal connectors with some specific examples of the various cases. The case with PS1 does not require any material with flame retardant. For all such low power circuits, the related internal connectors can have a UL94-HB rating. Such HB rated connectors of any shape, weight, color and manufacturer can be used in many different applications such as mobile phones, GPS Navigators, Cameras, MP3 players or PDAs. Following this recommendation allows an immediate implementation of Green Design.

Various such HB rated materials are available from many suppliers and can be chosen by the equipment designer or connector manufacturer based on the required electrical and mechanical performance. As a result, designers will not only have immediate access to a green plastic suitable for high temperature ranges, but will also be able to capitalize on the best balance between mechanical, electrical, and flow performance. Such HB rated high temperature polyamides also have higher toughness, better UV stability, higher CTIs and does not add any additional system cost.

Since PS2 and PS3 have sufficient power to ignite a combustible material as the isolating plastic between connector pins, precautions need to be taken to prevent ignition. In this case, connectors/sockets are distinguished by the weight of the combustible plastic used.

Only in case the weight of the plastic in the connector is above 4g, the IEC recommends a flame retardance of at least UL94-V1. Typical examples are e.g. the main power connector of a PC or CPU socket.

There are also connectors/sockets within a PS2 or PS3 application, which are no PIS. This can be the case if multiple connector/sockets are connected to each other or if additional components such as converters are used in the circuit. In such a case of no PIS, the connector/socket can not ignite itself and the only source of an internal ignition remains ignition from a different component. Therefore, the key fire safety precaution is its distance to another PIS. If the distance is higher than 50mm, then such a connector/socket is outside any critical distances and can be designed in UL94-HB rated material, irrespective of its weight. In case the connector/socket is within a critical distance of 50mm in proximity to another PIS, ignition can occur. If its weight is less than 4g, or if it should be located within a fire barrier, UL94-HB rated material can be used. In case the weight is higher than 4g, at least UL94-V1 needs to be used for the insulation material of such connectors/sockets.

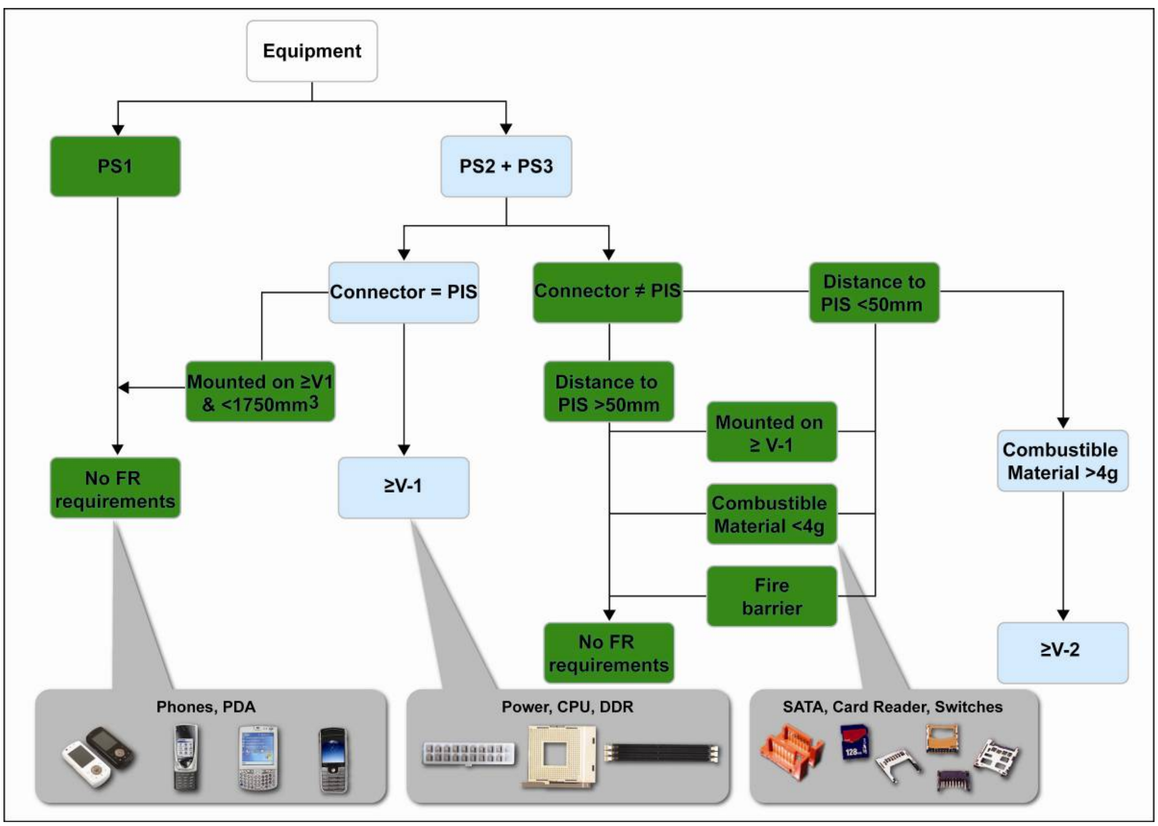

Figure 10: Control Fire Spread, internal connectors. Power level categorization and flame retardance requirements of internal connectors based on IEC62368 specification to control the spread of fire. For illustration some connectors and applications are illustrated.

Figure 10 shows a Green Design guideline to control the spread of a fire once a component has been ignited. While for PS1 circuits the IEC standard reveals a straight forward choice of UL94-HB material, a PIS in a PS2 or PS3 circuit is classified now by the volume of the connector and the flame retardance of the material where the connector/socket is mounted to. Since all standard PCBs are UL94-V0, the connector/socket can be UL94-HB if its volume is less than 1750mm^3. If the volume is higher, then at least UL94-V1 should be taken. This is the case e.g. for CPU sockets.

In case of no PIS in a PS2 or PS3 circuit, UL94-HB can be selected by designers if the distance between it and another PIS is higher than 50mm. If the distance is smaller than 50mm, UL94-HB can be selected in all cases where the connector/socket is mounted on a better than UL94-V1 rated PCB, and same is the case if the weight of the combustible plastic in this connector/socket is lower than 4g or if a fire barrier such as e.g. a metallic housing should be present in its circuit. Designers sometimes use metallic housings to shield critical PCB areas against electro magnetic interference. These housings are typically also fire barriers.

In case no fire barrier is present for a no PIS connector and the weight of the connector is higher than 4g, then a flame retardance of at least UL94-V2 is recommended.

Note that there is a distinct difference between the two different options of preventing ignition and controlling its spread. It is the choice of the designer or the design policy of the manufacturer to choose one of these two options.

Conclusions and Summary

In the conversion of the Electronic industry to halogen-free or low halogen applications, Connectors & Sockets as well as Cables & Wires remain the most challenging ones to highest mechanical and thermal performance requirements.

We believe that the new IEC62368 will lay the future implementations of adequate standards of safety and avoid potential product over specifications at early stages of design. As a material selection criterion and in terms of design guidelines, this can greatly help OEMs to implement Design for Low Halogen content.

Portable, small power applications such as mobile phones or cameras are the easiest to switch to halogen-free. Some applications have already made the switch, while others lag behind. Higher power applications such as desktops, notebooks and TVs, are more demanding due to the higher required power levels.

After having individual components in halogen-free, the next challenge is a complete halogen-free system. We are ready to support the electronics industry with halogen-free materials/components, both with FR V0, V2 and HB graded materials depending on the application requirements and OEM specifications.