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Adaption to scientific and technical progress under Directive 2002/95/EC

Results previous evaluation

Exemption No. 7 b

“a) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)

b) lead in solders for servers, storage and storage array systems,
network infrastructure equipment for switching, signalling, transmission as well as network management for telecommunications

c) lead in electronic ceramic parts (e.g. piezoelectronic devices)”

(Excerpt from ERA report 2004)

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2.2 Lead in solders for servers, storage and storage array systems, network infrastructure equipment for switching, signalling, transmission as well as network management for telecommunications (with a view to setting a specific time limit for this exemption)

2.2.1 Reason for exemption

Manufacturers of equipment that would be covered by this exemption request are concerned that the long term reliability of their products made using lead-free solders is not known and may be inferior to products made using tin/lead solder.

"Servers" is a term currently used to include all large computation systems and includes mini and midi systems as well as main-frame and super-computers. This equipment is essential for the operation of most businesses, government departments, hospitals, and many other organisations. These systems usually run continuously for at least 10 years and may be in use for 30 years. Continuous operation without downtime to repair faults is essential for many users. The cost of downtime to a bank or insurance company can be many millions of euros per minute. Servers are also used in hospitals, by the emergency services, for traffic control, to control railway signalling and for air traffic control where an unexpected defect could pose a serious threat to consumer safety. Server manufacturers aim to build machines which have typically less than 4 hours downtime over a 10 years life (source IBM).

Network infrastructure equipment is also essential for normal life. Telecommunications (e.g. public telephone networks) relies on a reliable network which does not fail. Unexpected failures could pose a threat to consumer safety if, for example, communications with the emergency services is not possible due to a break down within the system. This risk would occur if the failure was to the public network or in the private network at a fire station, doctor's surgery or hospital department.

There clearly could be a threat to consumer safety if the use of alternative lead-free solders were to result in Servers or Networks failing prematurely. The aim of this investigation, therefore, is to determine if premature failures are likely to occur and when manufacturers are likely to be able to use lead-free solders.

2.2.2 Definition of the scope of exemption

A definition has been produced in collaboration with manufacturers covering the following:

- servers, storage and storage array systems
- network infrastructure equipment for switching, signalling, transmission as well as network management for telecommunications
- definition of "solders"
- spare parts for repair, upgrade and re-use

2.2.3 Alternatives to lead in solders and concerns with the affect on reliability

Many different lead-free solders have been developed and several types are used in electrical equipment. A lead-free solder must contain metallic elements that are:

- Non hazardous
- Non reactive
- Not in very limited supply or very expensive
- Contain elements with melting point of about 1000°C or less

Only a very limited number of combinations of elements can fulfil all of these requirements.

Researchers have formulated and tested several hundred different alloys but all are different to standard tin/lead and there is no one alloy that can be used as a direct replacement that has identical properties. The main difference is that they have higher melting point but they are also harder, less ductile materials and solder wetting tends to be inferior. Some alloys contain zinc and have similar melting point to tin/lead but these are susceptible to corrosion. The addition of bismuth lowers melting temperature and improves wetting but causes difficulties with recycling, is difficult to repair or rework and can produce weak solder joints if lead is also present.

Some electrical equipment, mostly consumer electronics, is now being produced using lead-free solders but the types of PCBs used in Servers or Network equipment are larger and more complex and so more difficult to produce and are likely to be more susceptible to defects if all of the failure mechanisms are not understood and well controlled by the producer. In normal use, consumer electronics equipment is not used continuously for over 15 years without downtime unlike the equipment covered by this exemption request. Equipment manufacturers need to be aware of the differences between tin/lead and lead-free solders to avoid early failure of their products and modify production processes to compensate for these differences. This is more difficult with large, thick, very complex PCBs than with simpler types. The characteristics of PCBs from three types of electrical equipment are summarised in Table 2.

Table 2. Characteristics of PCBs

Characteristic of "typical" PCBs	Mobile phone PCB	Desktop computer PCB	Server or Network PCB
PCB thickness	0.5 mm	1 – 2 mm	Up to 10 mm, typically 2 – 4 mm
Number of layers in PCB	4 – 6	~12	>18 – 52
PCB size	30 cm^2	~900 cm^2	Various, up to 6200 cm^2
Types of components	Small low thermal mass	Mix of small and medium with a small number of large	Includes many larger high thermal mass components
Component density	High	Medium	High
SMT Reflow temperature required	235°C (used by Motorola)	~245 – 250°C (estimated)	260°C (sources: IBM, Lucent)

Component damage

Many electronic components have a limited upper temperature. While these are suitable for use with tin/lead solders, most lead-free alloys require a higher processing temperature which will damage some types of components. Tin/lead solder melts at 183°C whereas the lead-free solder most frequently recommended as the alternative is tin/silver/copper which melts at 217°C, which is **34°C higher**. This results in the temperature becoming much hotter during soldering processes which may exceed some components upper temperature limits.

Equipment manufacturers are able to minimise soldering temperatures to some extent by careful control of soldering conditions, the use of modern soldering equipment and ensuring that all surfaces to be soldered are clean and oxide free. However, the temperature of components on a PCB will depend on the characteristics of the PCB. Thin laminate with few layers and having only small, low thermal mass components such as in a mobile phone can successfully be manufactured, with state of the art ovens, at a temperature of 235°C. This is only 15 – 20°C higher than is normally used for tin/lead PCBs and at this temperature most components survive undamaged. However, when large, high thermal mass components or thick, multilayer PCBs. which also have a high thermal mass, are required, the board and components will need to be heated to up to 260°C. At this temperature, many components will be damaged.

Damage to plastic connectors and many other types of components will be obvious as connectors will be distorted and, if components are destroyed, the equipment will not function. However, some damage is not immediately apparent and failure occurs only after a period in service. Electrolytic capacitors lose electrolyte if over-heated which will shorten their life. Multi-layer ceramic capacitors are brittle and crack due to strain from thermal mismatch between board and component or if the PCB warps due to over-heating. This is not uncommon with tin/lead soldering but is likely to be more common with the higher temperatures needed for lead-free.

Component manufacturers are currently working to increase the upper temperature limit of their products and some new more heat resistant components have recently become available. However, it is likely that there will be some components used on the most complex Server and Network PCBs that cannot at present withstand the higher soldering temperature required for this type of PCB. Some manufacturers of Servers and Networks report that they have produced some types of PCBs with lead-free solders under laboratory conditions but have not been able to produce lead-free PCBs in a production environment, which would be essential for long-term reliability trials, partly due to the unavailability of heat resistant components.

PCB damage

The UK's National Physical Laboratory[7] has carried out research on the effect of soldering temperature on damage to PCBs. Their results showed that delamination and warping of PCBs increases with temperature. They also showed that failure of PCBs by a process called conductive anodic filaments (CAF) becomes increasingly more likely as the temperature increases. CAF is very uncommon with tin/lead solders.

Research also shows that damage to plated-through-holes (PTH) becomes more likely as the temperature increases. PTH are used to create electrical connections between layers within the PCB. These are made of copper which has a much smaller coefficient of thermal expansion than the laminate material itself in the z-axis (the direction of the PTH through the thickness of the board) and therefore strains are set up in the materials as the temperature changes.

Thermal fatigue

The temperature of circuit boards in most types of electrical equipment changes repeatedly during its life. This can be due to ambient temperature changes but this would not be the case for Servers which are used in air-conditioned and temperature controlled rooms. However, many components themselves produce heat and so when these are functioning, their temperature changes. Changes in temperature due to internally produced heat occur when components become active even when equipment is already switched on. Servers and Networks are usually required to run continuously but temperature changes occur due to the activation and deactivation of individual components. These temperature changes may occur a very large number of times during the life of a Server or Network PCB. These temperature changes are a problem because the TCE (thermal coefficient of expansion) of most components is different (and usually smaller) to that of the circuit board to which they are attached.

Temperature changes result in repeated cyclic strain on the solder bonds which can eventually cause it to produce cracks leading to an open circuit. This effect, illustrated in Figure 1, is called "thermal fatigue". Real examples of thermal fatigue failures are shown in Figure 2.

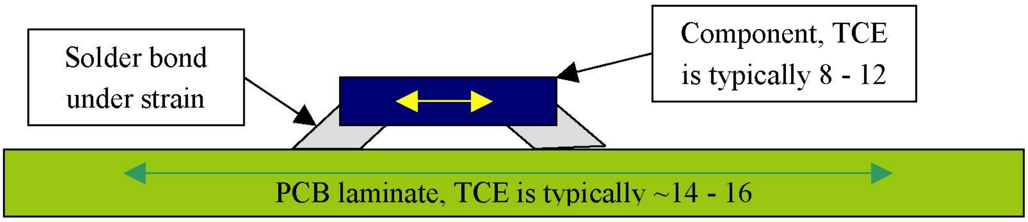

Figure 1. Schematic cross-sectional diagram of a component mounted on a board showing how temperature changes produce strain in the solder bonds.

Tin/lead solders have been used commercially in electrical equipment for many decades and their thermal fatigue properties are well understood. It is possible to carry out accelerated life tests on equipment made with tin/lead solders to determine the likely field life. This is possible because manufacturers have many years of experience with their products in the field so that accelerated tests can reliably predict field lives of tin/lead soldered products. It is not possible, however, to estimate field life expectancy from accelerated tests with lead-free solders because these solders have been used in mass produced electrical equipment for only a few years.

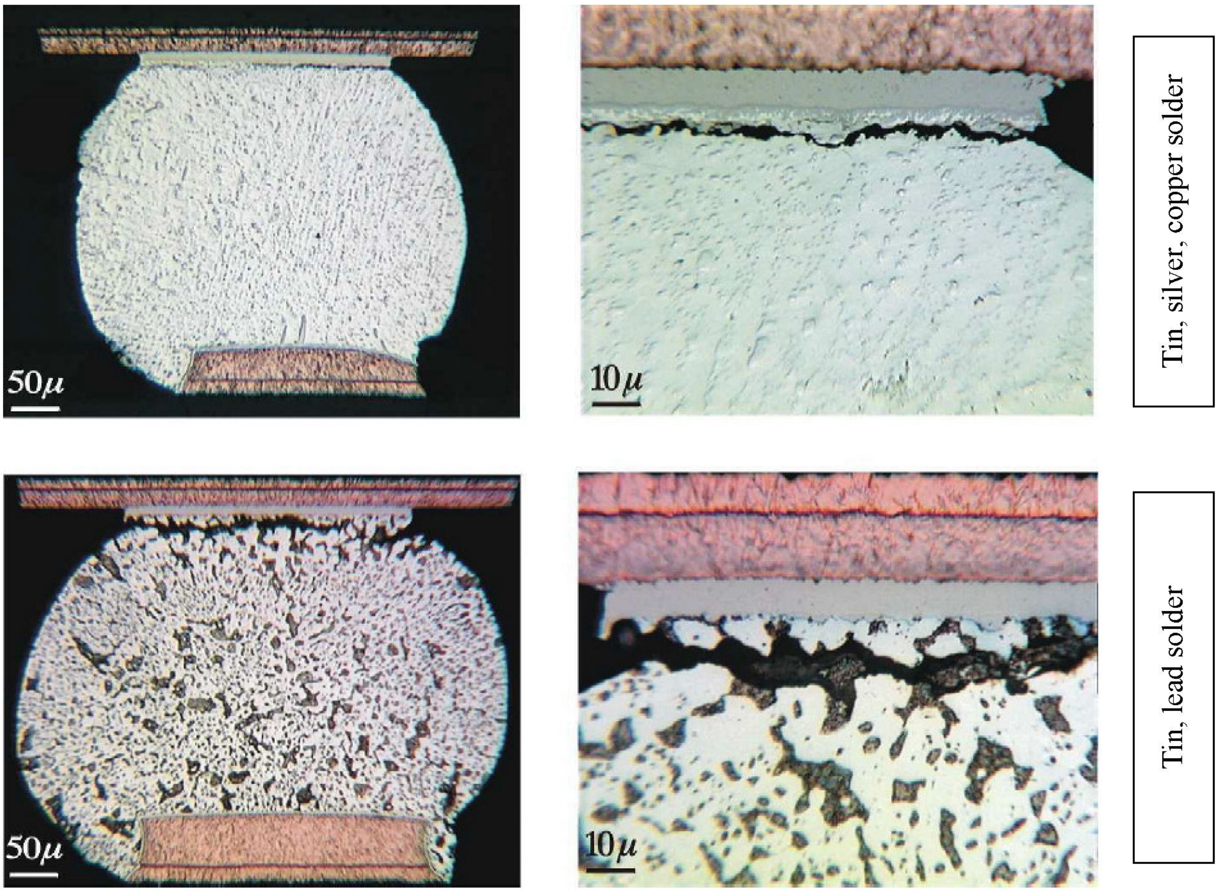

Figure 2. Ball grid array solder bonds that have failed by thermal fatigue. (Image from Cookson Electronics)

Accelerated life testing has been carried out with lead-free solders, however, and the results compared with tin/lead solder. Data from many investigations has been published and appears to show:

- Where there is a high strain, lead-free solder bonds fail after fewer cycles than bonds made with tin/lead solder.
- Where there is a low strain, lead-free solder bonds fail after more cycles than bonds made with tin/lead solder.

These results indicate that if high strain bonds can be avoided, reliability will be better with lead-free solders but the relationship between these accelerated tests and field conditions is unknown. High strain situations cannot be avoided, particularly with Servers and Networks which have large components soldered to PCBs. Therefore, if lead-free solders are used, there is an unquantified risk of premature failure due to thermal fatigue.

Comparison of accelerated test results from tin/lead and lead-free solders may be incorrect as the microstructure and creep behaviour of these alloys are different so that they cannot be directly compared. Accelerated tests use relatively short dwells to shorten the test time. It is during the upper temperature dwell that most creep occurs. It is known that creep of eutectic tin/lead is 10 – 100 times faster than lead-free solders and it is possible that these tests under-estimate the risk of thermal fatigue with lead-free solders[8].

To quantify this risk, equipment manufacturers will need to wait for field data to be received from a statistically meaningful number of pieces of equipment which has been in use for sufficient years in service. This data will enable them to determine the relationship between lead-free accelerated life test data and field life and establish whether lead-free soldered Servers and Networks can be used safely.

Tin whiskers

Tin whiskers have been known to occur on electroplated tin coatings for many years and have caused some well-publicised and expensive failures[9] (http://nepp.nasa.gov/whisker/failures/index.htm). Tin whiskers can cause short circuits in electrical equipment leading to either complete failure or intermittent faults. This potential problem was avoided in the past by using tin/lead coatings instead as tin because lead added to tin significantly reduces the susceptibility to whisker formation and, although tin/lead whiskers do occur, they are usually very short, so are not likely to cause a short circuit.

Causes of whiskers

It is fairly certain that tin whiskers are caused by stress within electroplated tin coatings. The exact mechanism is not well understood and there may be several underlying causes. It was at one time thought that "bright" tin was much more susceptible to whisker formation than "matte" tin coatings. Bright electroplated coatings usually do have more stress partly due to incorporation of organic compounds used to brighten the coating but recent research has shown that it is possible to produce bright tin with a low susceptibility and some matte tin coatings have been found to readily produce many long whiskers.

Tin deposited onto copper will form an irregular tin/copper intermetallic layer. As this grows, some research has indicated that this increases the strain in the tin coating which eventually causes whiskers. Some manufacturers now always electroplate tin onto a nickel barrier layer. Tin and copper form an intermetallic much more slowly and so whiskers are much less likely to form.

Humidity, voltage bias, tin thickness and the effect of heat (i.e. pre-baking or soldering) all influence whisker formation and growth and some of these variables are not fully understood.

Prevention of whiskers

NEMI[10] have published methods to prevent tin whiskers. One important characteristic of whiskers is their length. It is normally only long whiskers that cause short circuits and, frequently, whiskers are very short and would not cause a defect. NEMI's recommendations include:

- Use nickel/gold or nickel/palladium coatings instead
- Ensure that tin is electroplated over a nickel barrier layer (porosity free nickel has a thickness of a minimum of 1.27μm) of 2μm thickness.
- Hot dipped tin and electroplated tin that has been melted is not normally susceptible however these surfaces have inferior solder wetting properties and the high temperature can damage some components. Immersion tin is also not susceptible.
- Tin-plating bath chemistry is important. Generally matte tin is less susceptible than bright tin. However, some claim that bright tin coatings can be produced which have a low susceptibility. Also, some matte tin coatings can produce many long whiskers. Unfortunately there is currently no quick test for whisker resistance (the NEMI tests take 6 months).
- Tin plating on low TCE materials such as Alloy 42 and Invar is much more susceptible to tin whiskers due to the strain caused by the TCE difference between materials. It is best to avoid tin plating these materials.
- Tin-bismuth has a reduced tendency for whisker formation, especially after reflow, due to its lower melting temperature. The bismuth content should be <3% and thickness <8 μm if used with SnPb. It is best to avoid this composition if used with SnPb reflow as Bi may build up in solder pot.
- Tin thickness – NEMI recommends a thickness of > 8μm (without a nickel under-layer). Recent research has found that, with nickel, relatively thin tin coatings are preferable.
- Compressive stress is the cause of whiskers and so tin plating in tensile stress is preferable to tin in compression. Do not bend tin plated parts as this will cause compressive stress.

- Bias voltage is known to be detrimental to tin whiskers but the reason is unknown.

Effect on Servers and Networks

Equipment that incorporates components, which have electroplated tin coatings, is potentially susceptible to tin whiskers. Tin whiskers are generally 100 – 150 μm in length but can be much longer. Fine pitch components are the most at risk and many of these are used in these types of equipment.

NEMI have proposed accelerated tests for whisker susceptibility but these take six months and so cannot be used for quality control. Also, as with thermal fatigue, the relationship between these tests and field life over 30 years is not yet known.

Component manufacturers will endeavour to produce components with coatings that do not produce whiskers by careful control of tin electroplating bath conditions. However, as no rapid test is available, if an error occurs this could not be detected (by the six month test) until these components have been incorporated into equipment and is in use. Most component manufacturers use sub-contractors to tin plate lead-frames and so are not in an ideal position to control the plating process.

2.2.4 Exemption expiry dates

Equipment

Most manufacturers of Servers, Storage, Storage Arrays and Network equipment have stated that, in their opinions, they should have sufficient life data to be confident in the use of lead-free solders by 2010, although some Network equipment manufacturers have requested an expiry date of 2012 as long as these solders do not prove to be unexpectedly unreliable. Those Network manufacturers who have requested a later date manufacture products that use the largest and most complex PCBs. In this time, experience will be gained with other lead-free products such as personal computers and, if production of these start in 2005 as planned, there will be 5 years of field data available by 2010. Reliance on only five years field data may be relatively optimistic for products that can have a field life of up to 30 years but will at least show if the reliability predicted by accelerated tests is much worse than expected.

Spare parts for repair, upgrade or reuse

There is an additional issue concerning spare parts for repair, upgrade or reuse. Many of these will have been made at the same time as the original equipment and so will contain lead solders. Lead-free versions will not be available after 2010 or 2012 as many components will have become obsolete. Consequently, lead containing spare parts will have to be used after 2010 or 2012, as shown in Figure 3, to extend the life of these products. If this is not possible, the quantity of waste produced will be increased which contrary to the aims of both the WEEE and RoHS Directives as well as being very expensive for manufacturers and users.

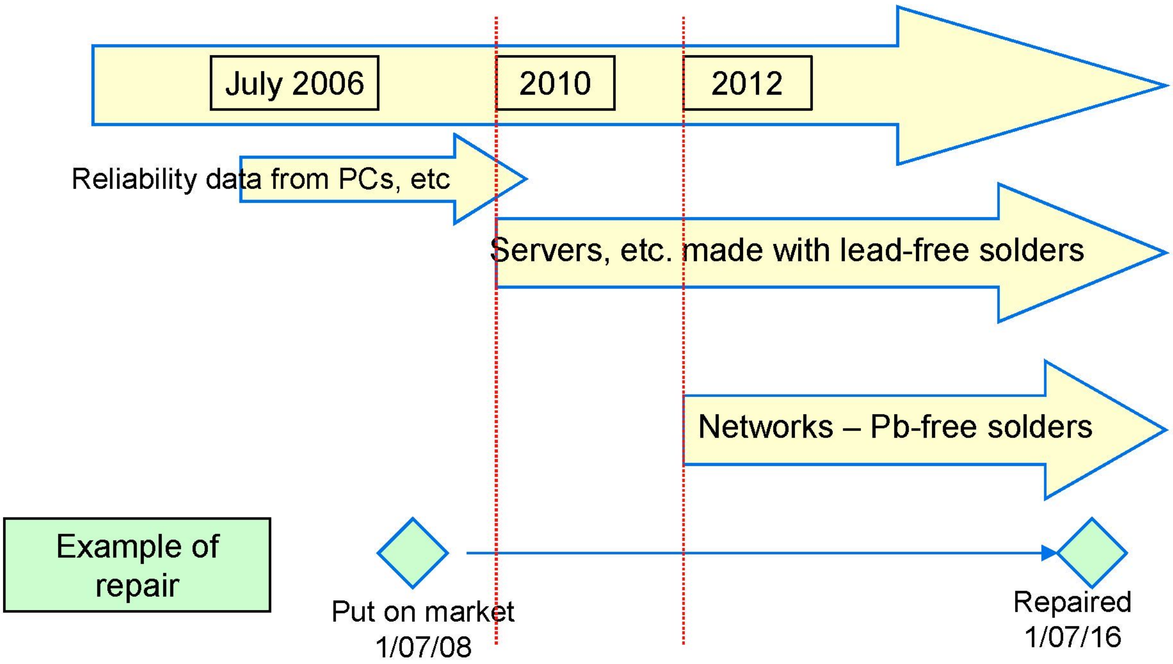

Figure 3. Road map for implementation of lead-free solders in servers, storage and storage arrays, and telecommunications networks

An alternative approach, which would get round this difficulty, is as follows:

1. Set no expiry date on this exemption.
2. Review this exemption again at least every four years as required by the RoHS Directive and so the next review should be no later than December 2008.
3. If this review finds that lead-free solders have been shown to be sufficiently reliable then terminate the exemption at this point. Otherwise, if reliability is still uncertain or frequent failures are encountered, then the exemption could continue - to be reviewed at least every four years until satisfactory reliability is achieved.

2.2.5 Definition of products covered by this exemption

A definition has been prepared, initially by manufacturers of these products and this has been amended in consultation with ERA to avoid potential loopholes. This definition, given in Appendix 1 of this report, covers those products that are currently on the market that should be included by this exemption and excludes those where it is not justified. There is a small risk that some manufacturers will design new equipment, such as desktop computers or telephones, to comply with this definition in order to avoid the need to use lead-free solders. Therefore this definition will need to be regularly reviewed.

2.2.6 Summary of the case for an exemption

Servers, storage and storage arrays and telecommunications equipment have characteristics which are different to most other types of equipment:

- their PCBs are larger, more complex and so more difficult to produce,
- the equipment is intended to operate continuously, often for over 10 years, without down-time,
- unexpected failures could create a risk to consumer safety.

Lead-free solders are available but they have been in use commercially for a relatively short time and the long-term behaviour in the field is unknown. Comparative accelerated test data for lead-free and tin/lead solders is available but there is uncertainty whether this can be relied on as lead-free solders and tin/lead solders have different micro-structures.

Manufacturers will have confidence that lead-free solders could be used in Servers, etc. when consumer equipment that will be produced with lead-free solders has been in use for five years without unacceptably high rates of early failures.

4. Proposed guidelines to define the scope of exemptions

The following sections provide clarification of the scope of each exemption.

4.1 Mercury in straight fluorescent lamps for special purposes

Straight fluorescent lamps not intended for general illumination. Examples include:

- LCD backlights
- Light sources in scanners, printers, photocopiers and fax machines
- Disinfection lamps
- Medical/therapy lamps
- Pet care lamps (such as those used within aquaria)
- Lamps for use at low temperature
- Extra long lamps which contain > 10mg of mercury
- Amalgam lamps

4.2 Lead in solders for servers, storage and storage array systems, network infrastructure equipment for switching, signalling, transmission as well as network management for telecommunications

A proposed definition of the scope has been produced by equipment manufacturers with input and some amendments by ERA. This is given in Appendix 1. Equipment that is covered by this exemption is of the type which is intended for continuous use for at least 10 years and has a high reliability. Personal computers, laptops, telephones, etc. are not covered by this exemption.

4.3 Light bulbs

This refers to filament or incandescent light bulbs. These can be included in the scope of the RoHS Directive. An exemption for one type of filament lamp has been reviewed. These are straight filament lamps that use lead to attach a silicate coating to the interior of the glass tube.

4.4 Compliant pin connector systems

This title has been rewritten since “VHDM” is a trade mark and this exemption request is for all types of compliant pin and press-fit connectors. Compliant-pins are used as connections in multi-way connectors. The compliant pins are of various designs and have electroplated tin or tin/lead coatings which are inserted into a matching array of plated through holes in printed circuit boards to make an electrical and mechanical connection. These connectors are designed to make multiple reliable

APPENDIX 1. Scope of exemption: Lead in solders for servers, storage and storage array systems, network infrastructure equipment for switching, signalling, transmission as well as network management for telecommunications

1. Definition of “Solders”

Alloys used to create metallurgical bonds between two or more metal surfaces to achieve an electrical and/or physical connection. The term “solder” also includes all materials that become part of the final solder joint, including solder finishes on components or printed circuit boards. This exemption applies to alloys containing tin and/or lead used as “solder”, as board coatings and as component termination coatings.

2. Definition of "server" product for the purpose of RoHS exemption:

A "server" is defined as a computer that meets one of the technology criteria set out in section (a) below, and one or more of the functional criteria set out in section (b) below.

(a) Technology Criteria For Server

Designed and placed on the market as a Class A product per EuroNorm EN55022:1994 under the EMC Directive 89/336/EEC (whereas a Class B product is intended primarily for use in the domestic environment) and designed and capable of having a single or dual processor capability (1 or greater sockets on board).

Or

Designed and placed on the market as a Class B product per EuroNorm EN55022:1994 under the EMC Directive 89/336/EEC and designed and capable of having a minimum dual processor capability (2 sockets on board).

(b) Functional Design Criteria For Server

i. Designed and capable of operating in a mission-critical, high-reliability, high-availability application in which use may be 24 hours/day and 7 days/week, and unscheduled downtime is extremely low (minutes/year).

Examples of typical server functions are given in items *ii* to *ix*:

ii. Designed and capable of operating in a multi-user environment in which access to the computer or accompanying storage or storage array is not required of the user; or

iii. Designed and capable of operating as an intermediate step to process information, i.e. takes input from another system, processes that input, and passes it on to another system for further processing; or

iv. Designed and capable of operating to provide network infrastructure services, (e.g. archiving); or

v. Designed and capable of operating to provide gateway or switching services; or

vi. Designed and capable of operating to host data on behalf of multiple users; or

vii. Designed and capable of operating to allocate or manage user id's that can be used for remote logons, i.e. where physical access to the system is not required by the user; or

viii. Designed and capable of operating to run a server-capable operating system (e.g. Windows NT, Windows 2000 Server, OS/400, OS/390, Linux, Unix and Solaris); or

ix. Designed and capable of operating as a web server.

The exemption applies to the whole of the computer and its components including processors, memory boards, power converters, power supplies, enclosed housings, modular power subsystems and adapter cards. It also applies to the components as integrated into the whole computer or as sold separately for use in an exempt server. Cables and cable assemblies, and all connectors and connector assemblies used to provide interconnections for the server are also covered.

It should be noted that this exemption does not apply to parts or components that are peripheral to the server, nor does it apply to parts or components when they are used other than in an exempt server, storage or storage array system or networking product.

3. Definition of storage and storage array systems

EICTA recommends that "storage and storage array systems" be defined as any device or subsystem that meets at least <u>one</u> of the functional criteria (a) and <u>one</u> of the technology criteria (b) as set out below. The exemption applies to the whole of the device or a subsystem, including, but not limited to disc drives, disc arrays, tape drives/libraries and automated management.

(a) <u>Functional Design Criteria for storage and storage array systems</u>:

i. Designed and capable of operating in a mission-critical, high-reliability, high-availability application in which use may be 24 hours/day and 7 days/week, and unscheduled downtime is extremely low (minutes/year).

Examples of typical storage and storage array functions are given in items ii through iv:

ii. Designed and capable of operating in a multi-user environment in which access to the storage or storage array is not required of the user; or

iii. Designed and capable of operating to provide network infrastructure services, (e.g. archiving); or

iv. Designed and Capable of providing long term data archival storage such as regulatory and/or compliance records as required by US and EU laws.

(b) Technology criteria for storage and storage array systems:

Designed and placed on the market as a Class A product per EuroNorm EN 55022:1998 under the EMC Directive 89/336/EEC

Or

Designed and placed on the market as a Class B product per EuroNorm EN55022:1998 under the EMC Directive 89/336/EEC and designed and meets one of the following criteria:

1. Any storage device or storage management device capable of accepting direct or switched input from more than one computer. As examples, but not limited to, fibre channel and SCSI devices allow for direct or switched input from more than one computer or

2. Any storage fabric or switching device for interconnecting storage devices to server products.

4. Definition of Network Infrastructure for the purpose of RoHS

In the Annex of Directive 2002/95/EC the use of lead in solders for telecommunication network infrastructure equipment is exempted. In order to define the boundaries of the telecommunication network infrastructure a number of manufacturers have taken the initiative to provide a recommendation as included in this document.

We recommend that the equipment falling under the "network infrastructure equipment" for telecommunications exemption would be defined according to functionality of the product. Telecommunication network infrastructure equipment can be located well beyond the service providers' network demarcation points. As such, the lead-free exemption for network infrastructure equipment under RoHS should be based on long-term capital investment, reliability, availability and operability issues that must be addressed by all operators (service providers and private companies).

Network infrastructure equipment is defined as *professional equipment* used for the provision of *telecommunication* services between a number of locations, where

The term "*professional equipment*" is defined as equipment, which has been designed primarily to serve high-reliability and availability public and business applications and which meets at least one of the two following criteria:

- Any system used for routing, switching, signalling, transmission, network management or network security in telecommunication applications;

- Any system which can simultaneously enable more than one end-user terminating equipment to connect to a telecommunication network;

And any system in a network **except** for end-user terminating equipment such as voice terminals, personal computers, facsimile machines, mobile phones, personal digital assistants, consumer-type modems and routers, and TV set-top boxes.

This includes all components, power supplies, display devices and similar electronic units that are incorporated into network infrastructure equipment. It also includes all cables and cable assemblies and all connectors and connector assemblies use to provide interconnections for telecommunication network infrastructure equipment.

The term "*telecommunication*" is defined as information transfer according to agreed conventions by means of wires, radio, optical or other electromagnetic systems. Any transmission, emission or reception of signs, signals, writing images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems. (Source: IEC 60050-714).

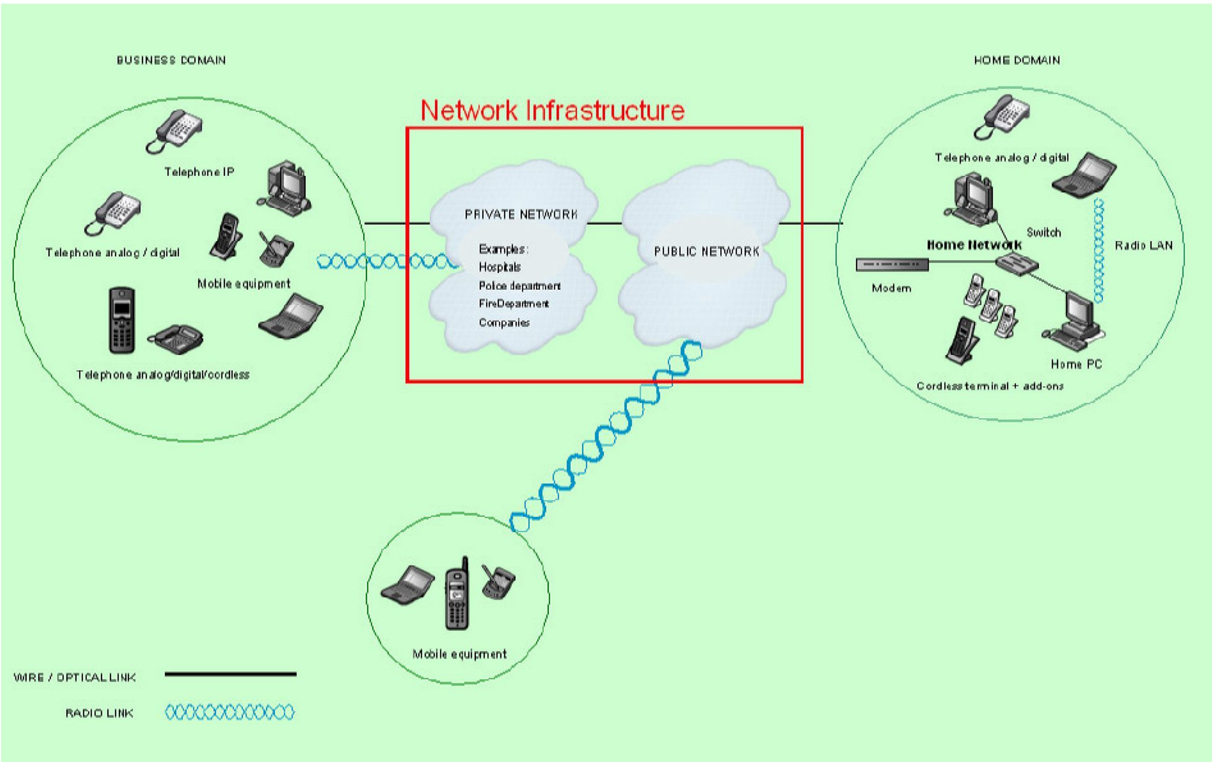

Figure 21. Boundaries in a typical telecommunications network for RoHS exemption