Soldering of SMD Film Capacitors in Practical Lead Free Processes

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INTRODUCTION

Today the lead free soldering process is a must in commercial electronics and it is also coming more and more important in automotive and industrial electronics sectors in the near future. The most common choices for lead free solders are different Tin-Silver-Copper (SAC) alloys. Processes using SAC solders cause extra stress, because of increased process temperatures, especially to the plastic materials.

This paper describes the possibilities to use Metallized Plastic Film Capacitors in lead free soldering process. Presentation describes the different dielectric film materials for SMD capacitors, which are commercially available on the market today, and gives overview of their characteristics. The paper also gives an overview of the practical lead free soldering process using SAC solders, and of the possibilities to optimize process parameters in order to achieve optimum soldering conditions. A software tool is described to help in this optimization.

PLASTIC FILM DIELECTRICS SELECTION

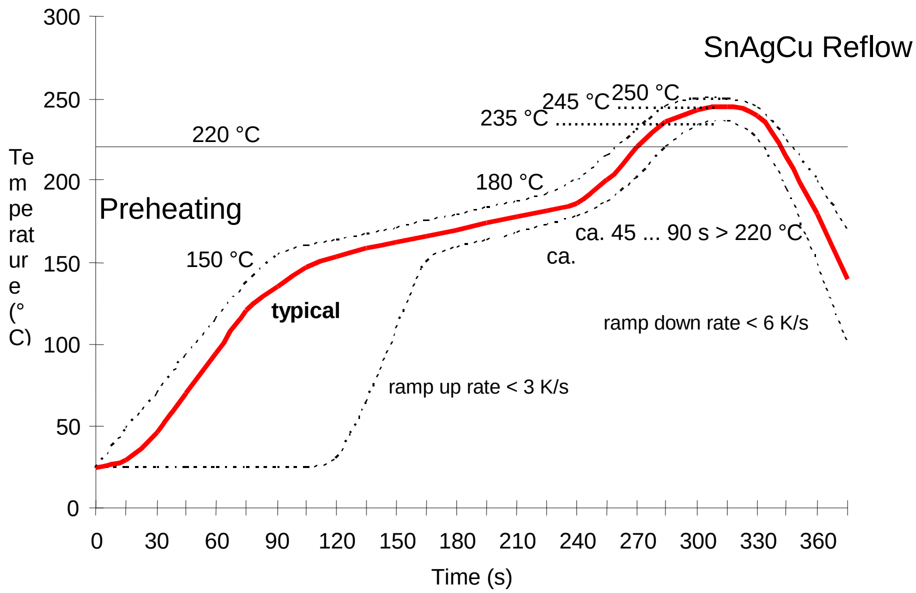
The selection of possible plastic film dielectric materials was made based on their temperature characteristics and commercial availability. The candidates were Polyethylene terephthalate (Polyester) (PET), Polypropylene (PP), Polyethylene naphthalate (Polyester) (PEN), Polyphenylene sulphide (PPS), Polyimide (PI), and Polytetrafluoroethylene (PTFE).

PP has the drawback of low melting point (160 – 170 ºC), which rules it out from high temperature soldering process i.e. reflow soldering process. PI and PTFE films are not commercially available as thin films (< 6 µm), and are very difficult to metallize properly. This is why they were not considered as viable candidates, although their high temperature characteristics are very good. In the Table 1. the selected characteristics of the remaining PET, PEN and PPS films are given.

Film material	**PET**	**PEN**	**PPS**
Dielectric constant	3,3	3	3
Dissipation factor (%/1kHz)	0,5	0,4	0,05
Insulation resistance (MΩ*µF)	>25k	>25k	>50k
Dielectric absorption (%)	0,5	1,2	0,05
Melting point (°C)	254	266	285
Min commercial thickness (µm)	0,9 (0,7)	1,2	1,2

Table 1. Film Dielectric Properties

Figure 1. shows typical recommended process conditions for Pb-free reflow soldering (SnAgCu solder alloys) taken from a document IEC 61760-1, Ed. 2. (Ref 1) The test specifications for resistance to soldering heat often have higher peak temperatures than in the Figure 1. The Pb-free processes are anyhow still under development, especially the soldering machine temperature controls, and it is still to be seen what the status quo will be. It may be that several component groups require special handling. A general opinion is that for good soldering the solder should stay 20 s at least above 230 ºC (Based on IEC 60068-3-12-TR-Ed.1) (Ref 2). Lack of this document is that only molded active electronic components are included in the study.



Continuous line: typical process (terminal temperature)

Dotted line: process limits; Bottom process limit (terminal temperature) Upper process limit (top surface temperature)

Figure 1. Recommended reflow soldering curve for SnAgCu solders taken from IEC 61760-1, Ed 2

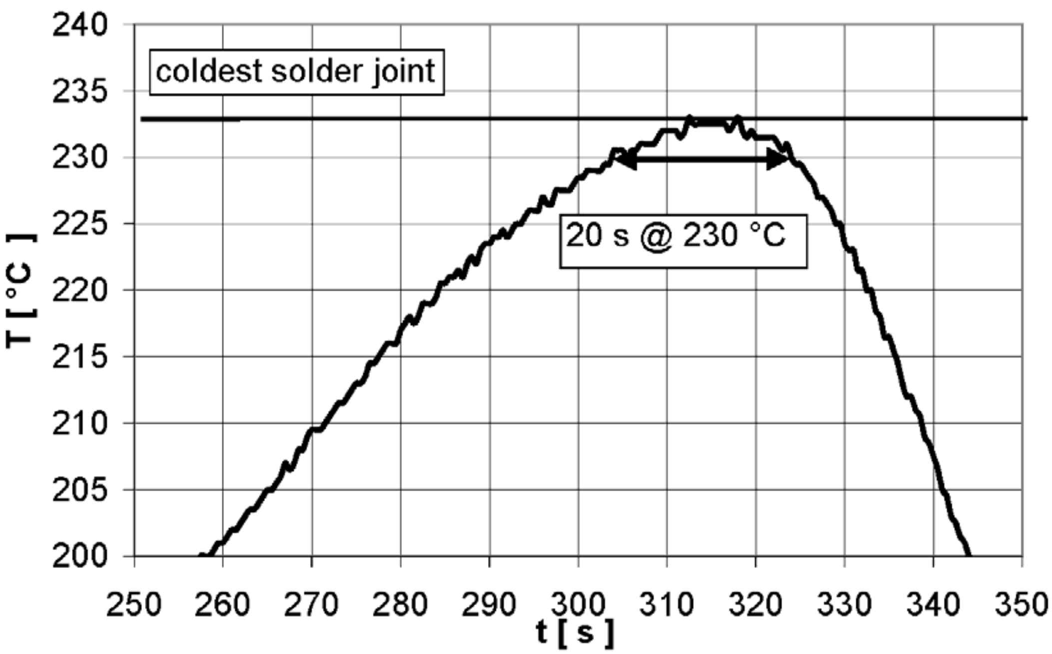


Figure 2. Curve shape for a peak temperature of at least 20 s for SnAgCu (SAC) solders taken from IEC 60068-3-12-TR-Ed.1

Other typical referred standards are IEC 60068-2-58 Tests – Test Td- Test methods for solderability, resistance to dissolution of metallization and to soldering heat of surface mounting devices (SMD) and IPC/JEDEC J-STD-020C July 2004 Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices. IEC 60068 outlines test Td, applicable to surface mounting devices (SMD), to as specimens, which are intended to mount on substrates. This standard provides the standard procedures for solder alloys containing lead (Pb) and for lead free solder alloys. The purpose of JEDEC J-STD-020C standard is to identify the classification level of non-hermetic solid state surface mount devices (SMDs) that are sensitive to moisture-induced stress so that they can be properly packaged, stored, and handled to avoid damage during assembly, solder reflow attachment, and/or repair operations. Both of these standards define also guidlines for SAC reflow soldering process. These conditions differ a bit of earlier mentioned IEC 61760-1, Ed 2 recommendations. Anyhow IEC 61760-1, Ed 2 has been guideline for Evox Rifa development work to develop SMD film capacitors, which are capable to withstand lead free reflow soldering process temperatures. IEC 61760-1, Ed 2 has been chosen because it defines that a wide variety of SMDs (passive and active) can be subjected to the same placement and mounting processes during assembly. It also defines tests and requirements that need to be part of any SMD component general, sectional or detail specification. Further this standard provides component users and manufacturers with a reference set of typical process conditions used in surface mount technology.

CONSTRUCTION OF SMD FILM CAPACITORS

The basic construction of a winding is in Figure 3., where two metallized films are wound together to form a winding. The metallizing material is typically Aluminium, and the round winding is normally flattened in a heat treatment process to form a suitable and inert package for further processing.

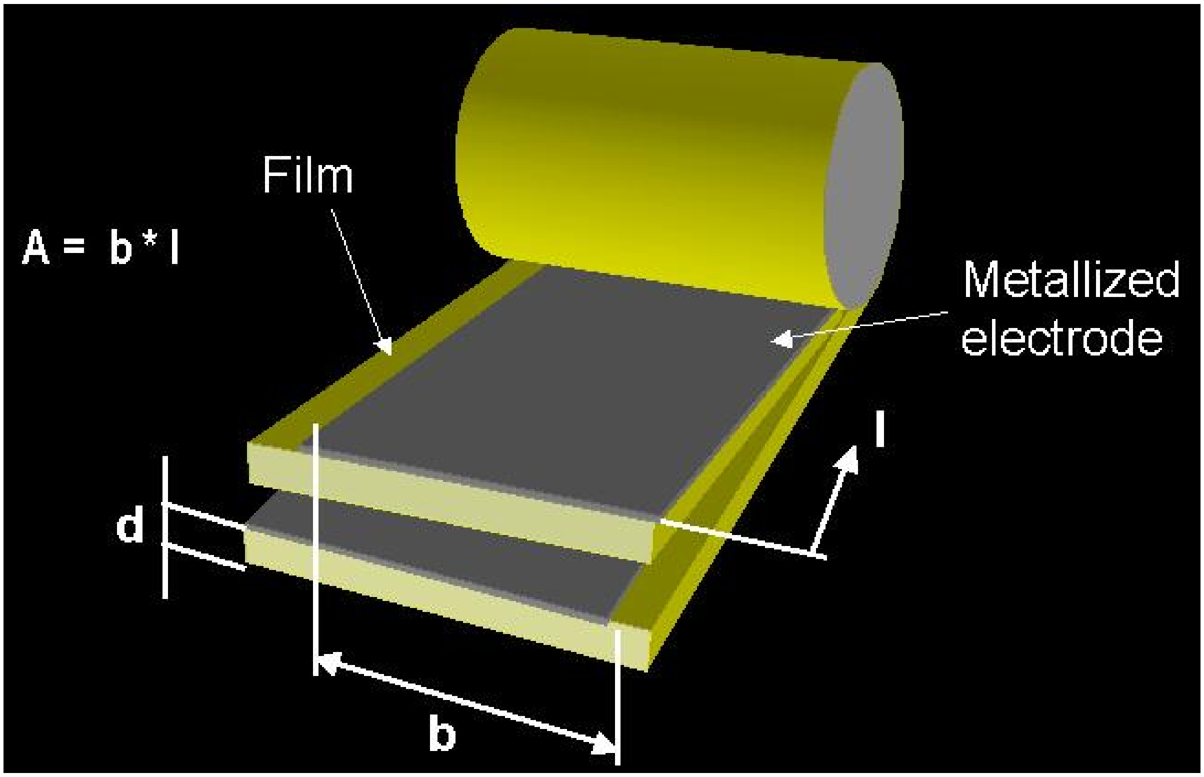


Figure 3. Winding

The flattening and heat treatment process is the most important one to prepare the capacitor especially for the reflow soldering process, and for the long time service in high temperatures.

The flattening and heat treatment are not discussed in detail here. It is essential by correct treatment to guarantee that the process temperature / time in the reflow soldering are not affecting the capacitor element. At the same time it should not by no means deteriorate the film's polymer structure, which could cause long-term reliability problems.

The electric contacts to the flattened winding are made by spraying molten metal to the ends of the winding. This metal makes contact with the metallized electrodes on both films separately. There are normally at least two different sprayed metal layers on both ends: contact layer to winding, typically Aluminium, and solderable layer towards outer electrode. The high process temperatures in SAC reflow soldering have put their own requirements on the solderable layer, and the material tests to optimally cope with these requirements.

The capacitor element is encapsulated in pre-moulded box, which is of glass reinforced PPS material. The potting of the element in the box is made with specially selected halogen-free epoxy. Both the box and the epoxy are self extinguishing materials. The Figure 4. shows an end-sprayed capacitor element, box, element with outer electrodes attached, and the ready made capacitor without epoxy potting.

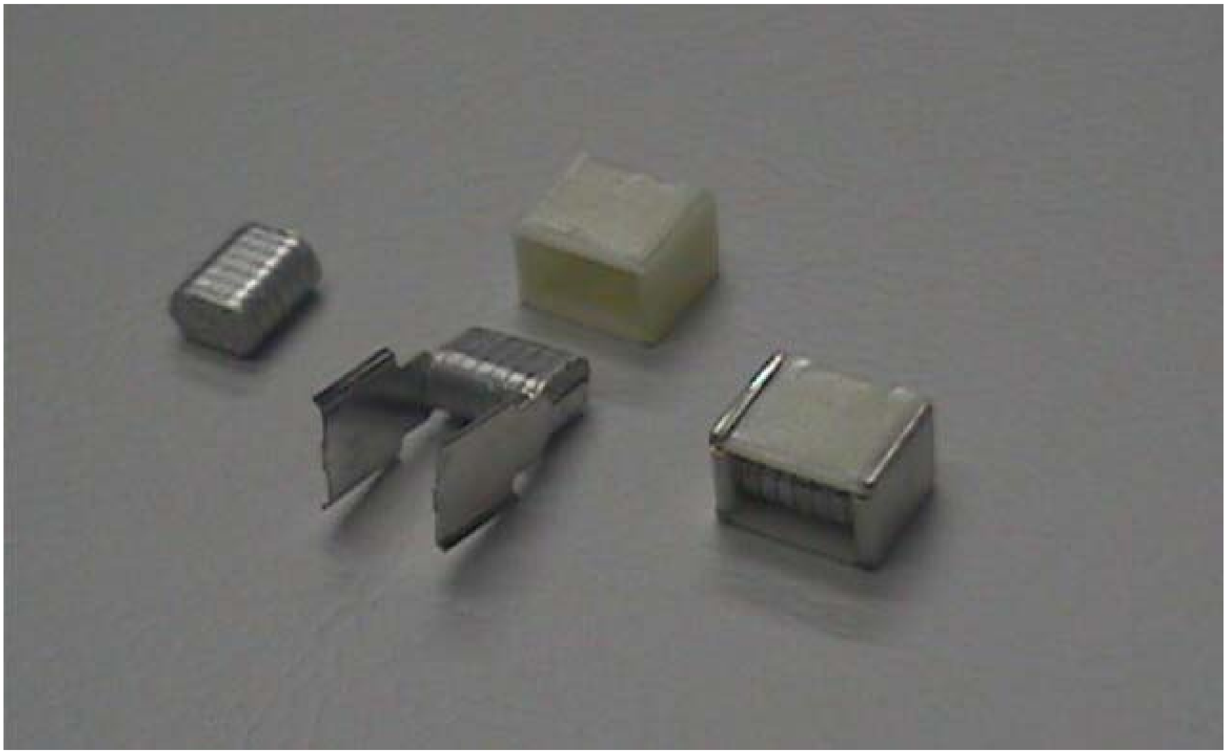


Figure 4. Capacitor construction

The sizes, which are available from Evox Rifa today, are shown in the Table 2.

Size code	L(mm)	B(mm)	H(mm)
2220	5,7	5,0	2,5-4,0
2824	7,3	6,0	2,5-4,5
4036	10,2	9,1	5,5
5045	12,7	11,5	6,5
6560	16,5	15,0	7,0

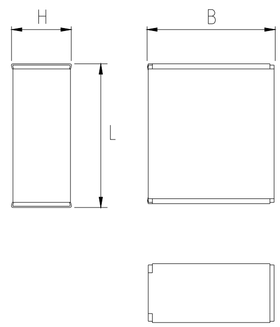


Table 2. Sizes of capacitors

Processes using SAC solders cause extra stress, because of increased process temperatures and also longer time in pre-heating/soldering peak creating more temperature stress to components. PET, PEN and PPS films are used in Evox Rifa SMD film capacitors, because of lead free soldering process temperatures are possible to optimize below these material melting temperatures. Temperature stress is the biggest challenge to using SMD film capacitors in lead free soldering process. Below is listed how earlier mention standards define temperature measurement.

According to IEC 61760-1 (Ed 2):

- The maximum temperature, measured **on the top surface of a component** shall not exceed the upper process limit to avoid component damage by heat exceeding the component's resistance to soldering heat specification.

According to IPC/JEDEC J-STD-020C July 2004:

- **All temperatures refer to topside of the package, measured on the package body surface**

According IEC 60068-2-58:
Reflow temperature profile for resistance to soldering heat

- Unless otherwise specified in the relevant specification, **the temperature shall be measured at the specimen's top body surface.**

Reflow temperature profile for wetting

- Unless otherwise specified in the relevant specification, the temperature shall be measured at the specimen termination. When semiconductor SMDs are examined, the temperature shall be measured at the SMD's top body surface.

Standards defines only place where to measure temperature, but any of the international standards do not define how the thermocouple should be fastened on the component. Evox Rifa has made a lot of studies for different type of fastening methods. Following measurement shows that it is important to define how thermocouple should be fastened. Figure 5. shows tested fastening methods and Figure 6. gives measured temperature curves from reflow oven. Table 3. shows measured peak temperatures using five different fastening methods. According to this test Aluminium (Al) tape fastening gives the lowest temperature on the top surface of capacitor only 230,0 °C and the highest temperature is measured using Capton tape 248,9 °C. Difference is 18,9 °C which is significant! All other fastening methods give readings between these two extremes. The test was reproduced many times to confirm repeatability.

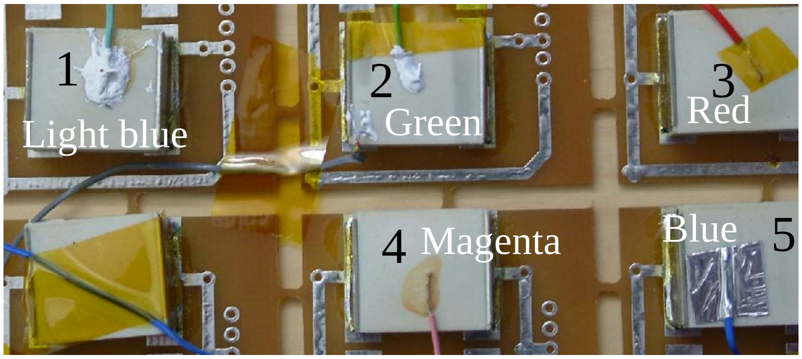


Figure 5. Five different thermocouple fastenings on the top surface of SMD film capacitors.

List of the used fastening methods in Fig 5.

1 glue + heat transfer paste
2 heat transfer paste
3 Capton tape
4 glue
5 Al tape

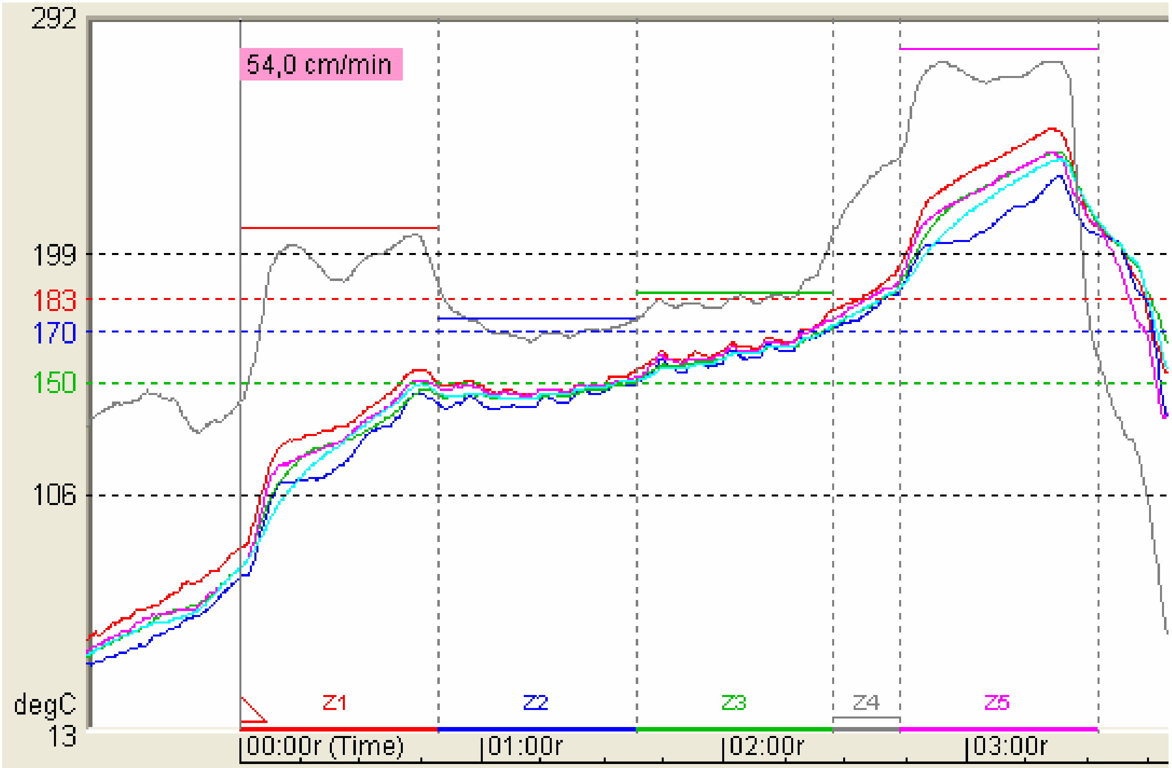


Figure 6. Reflow temperature curves from different fastening methods

Sensor Locations	Peak
Capton	248,9
Al tape	230,0
heat transfer paste	240,0
Glue	239,4
Glue and heat transfer paste	237,2
Air	275,0

Table 3. Peak temperature results from reflow test

Based on this study Evox Rifa has started to use in own laboratory fastening method glue + heat transfer paste. This method is used also in various customer measurements in the field. Reproducible thermocouple fastening method is first step to measure correct temperature on the top of capacitor or any other component. All Evox Rifa SMD film capacitors are manufactured using wound technology. The basic construction of a winding is in Figure 3., where two metallized films are wound together to form a winding. This part of construction is the most sensitive for heat stress in lead free soldering process. Table 1. defines melting temperatures for plastic film materials: temperature inside of winding must be below these temperatures. Maximum allowed temperatures on the top of capacitors are defined so that temperature inside of winding stays below plastic film melting temperature. Several measurements of the heat transfer from the top of the capacitor to inside of the winding have proved, that it is possible to define a constant factor. The constant depends on the size of the product. This information led us to start collaboration with POHTO/Training Factory for the Electronics Industry making simulating program to Evox Rifa. POHTO has created simulating tool for defining temperature on the top of capacitor if solder temperature is measured in process. Manufacturing industry measures always solder temperature, because it is their interest to make good soldering joint. A component manufacturer needs to know what is the highest temperature that the component sees in the reflow process. The highest temperature is on the top of component. As the international standards define temperature on the top of component, Evox Rifa has defined also all SMD temperature curves on the top of capacitor. Simulating tool has been very useful tool optimizing different reflow processes. The Tool gives possibilities to minimize heat stress to Evox Rifa capacitors, and also all other component heat stresses. SMD film capacitor is not the only heat sensitive component. Here are few examples of other heat sensitive components: relays, opto-couplers, crystal oscillators, LEDs, plastic connectors, some ICs and electrolytic capacitors.

Practical reflow process temperature for SMD capacitors is showed in Figure 7. Green curve is made based on Evox Rifa's experience from the field measurements. Blue curve is defined according IEC 60068-3-12-TR-Ed.1. Based on Evox Rifa's experience 30 s above SAC-alloy melting point (217 °C) is enough to create good soldering joint. Figure 8. shows all Evox Rifa's reflow temperature curves for all SMD film materials. Blue curve is according to IEC 60068-3-12, Green curve 30 s above 217 °C, Light blue for PET dielectric (peak 240 °C), darker blue for PEN dielectric (peak 250 °C), dark green for PPS dielectric (peak 260 °C). All SMD reflow curves Evox Rifa has defined follow IEC 61760-1, Ed 2 guidelines.

Reflow peak temperature

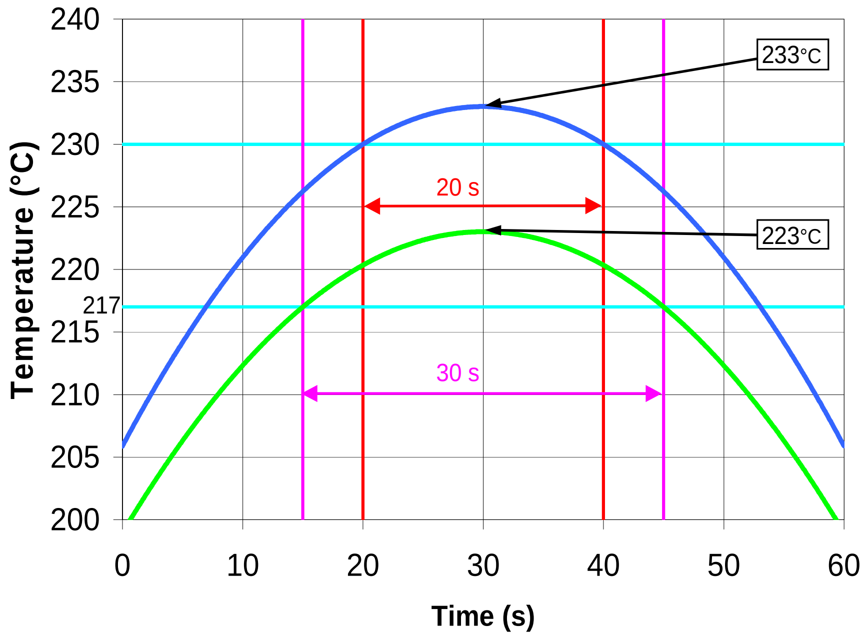


Figure 7. Practical reflow peak temperature based on Evox Rifa's experience (green)

Reflow peak temperature

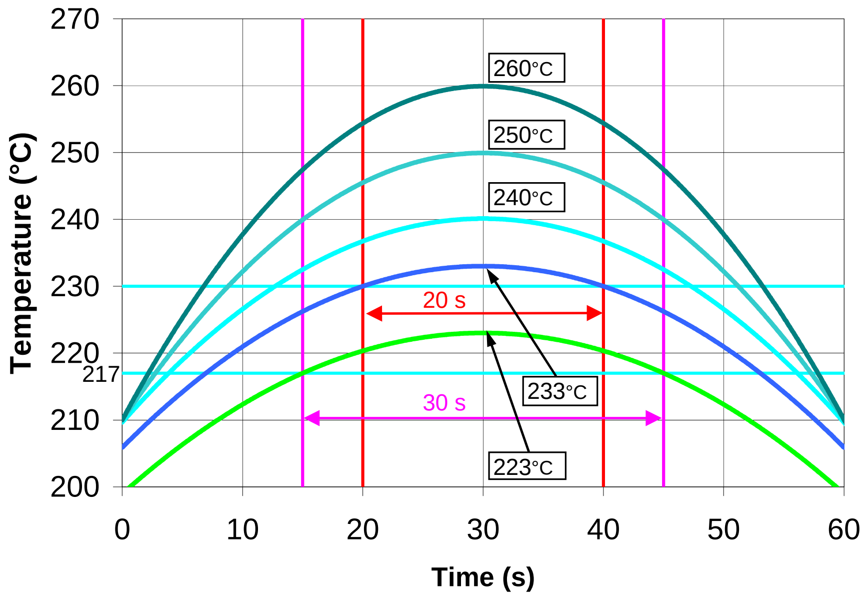


Figure 8. Comparison between IEC 60068-3-12-TR-Ed1 and Evox Rifa PET, PEN and PPS Curves

SUMMARY

When lead free is a must, it will be more and more important to use reflow ovens, which are designed for lead free process. If an old reflow oven is used in reflow process, this oven's temperature control is not good enough and in most of the cases it doesn't guarantee good soldering joints. It is possible to use older reflow ovens, if reflow profiling is made carefully with every board, which goes into the process. It is also important to concentrate in PCB thermal design to minimize temperature variation over the board. Delta T is the most important factor when thermal design is made. Traditional PCB design tries to increase component density over the board. Lead free process demands will create new rules to make good PCB's, but unfortunately it takes some time to realise all this. For component manufacturers lead free means needs to develop components at higher and higher process temperatures, but there are limits for these temperatures, too. The companies, which use components in lead free process, have demands usually for temperature capability as high as possible even when components don't survive high temperatures.

There are also some companies, who are producing very high quality and reliable products and these companies approach is totally different. These companies want to use as low temperature as it is possible to make reliable soldering joints in lead free soldering process. Another advantage apart from lower temperature reducing the risks of electrical failures in the process is the reduced possibility of latent defects in the long term. Although this is something we yet have very little practical experience of.

REFERENCES

1. IEC Publication 61760-1, Ed.2: Standard Method for the specification of surface mounting components (SMDs), International Electrotechnical Commission, 2006, Geneve, Switzerland
2. IEC Technical Report 60068-3-12,Ed.1: Development of a possible lead free qualification reflow temperature profile, International Electrotechnical Commission, 2007, Geneve, Switzerland