Soldering Recommendations for Surface Mount and Multilayer Metal Oxide Varistors

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Introduction

In recent years, electronic systems have migrated towards the manufacture of increased density circuits, with the same capability obtainable in a smaller package or increased capability in the same package. The accommodation of these higher density systems has been achieved by the use of surface mount technology (SMT). Surface mount technology has the advantages of lower costs, increased reliability and the reduction in the size and weight of components used. With these advantages, surface mount technology is fast becoming the norm in circuit design.

The increased circuit densities of modern electronic systems are much more vulnerable to damage from transient overvoltages than were the earlier circuits, which used relays and vacuum tubes. Thus, the progress in the development of faster and denser integrated circuits has been accompanied by an increase in system vulnerability. Transient protection of these sensitive circuits is highly desirable to assure system survival. Surface mount technology demands a reliable transient voltage protection technology, packaged compatibly with other forms of components used in surface mount technology.

Harris Suppression Products has led the field in the introduction of surface mount transient voltage suppressors. These devices encompass voltages from $3.5V_{DC}$ to $275V_{AC}$ and have a wide variety of applications. Their size, weight and inherent protection capability make them ideal for use on surface mount printed circuit boards.

There are two technologies of Littelfuse surface mount surge suppressors. The CH Series metal oxide varistors which encompass voltages from $14V_{DC}$ to $275V_{AC}$ and the ML, MLE, MLN and AUML Series Suppressors which cover a voltage range from $3.5V_{DC}$ to $120V_{DC}$.

Metal Oxide Varistors

A metal oxide varistor (MOV) is a nonlinear device which has the property of maintaining are relatively small voltage change across its terminals while a disproportionately large surge current flows through it (Figure 1). When the MOV is connected in parallel across a line its nonlinear action serves to divert the current of the surge and hold the voltage to a value that protects the equipment connected to the line. Since the voltage across the MOV is held at some level higher than the normal line voltage while surge current flows, there is energy deposited in the varistor during its surge diversion function.

The basic conduction mechanism of a MOV results from semiconductor junctions (P-N junctions) at the boundaries of the zinc oxide grains. A MOV is a multi-junction device with millions of grains acting as a series parallel combination between the electrical terminals. The voltage drop across a single grain in nearly constant and is independent of grain size.

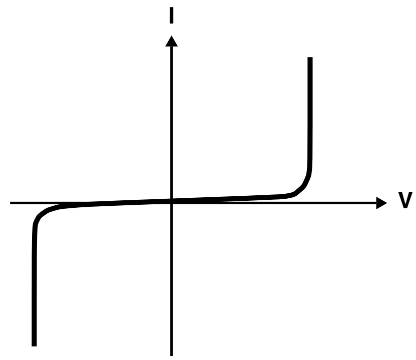

FIGURE 1. V-I CHARACTERISTICS OF A MOV

The CH series of surface mount metal oxide varistors are of a monolayer construction in a 5mm by 8mm package size. They are fully symmetrical and are passivated both top and bottom (Figure 2). The main advantage of this technology is its high operating voltage capability ($68V_{DC}$ to $275V_{AC}$). The CH Series of metal oxide varistors are supplied in both 7" and 13" tape and reels.

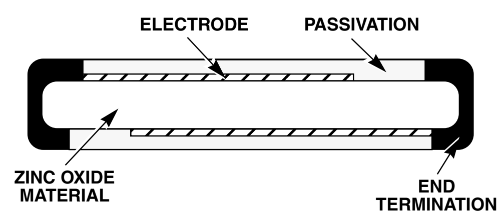

FIGURE 2. CROSS-SECTION OF THE "CH" SERIES OF METAL OXIDE VARISTORS

Multilayer Transient Voltage Suppressors

All Littelfuse multilayers are constructed by forming a combination of alternating electrode plates and semiconducting ceramic layers into a block. This technology, represents a recent breakthrough in its application to transient voltage suppression. Each alternate layer of electrode is connected to opposite end terminations (Figure 3). The interdigitated block formation greatly enhances the available cross-sectional area for active conduction of transients. This paralleled arrangement of the inner electrode layers represents significantly more active surface area than the small outline of the package may suggest. The increased active surface area results in proportionally higher peak energy capability.

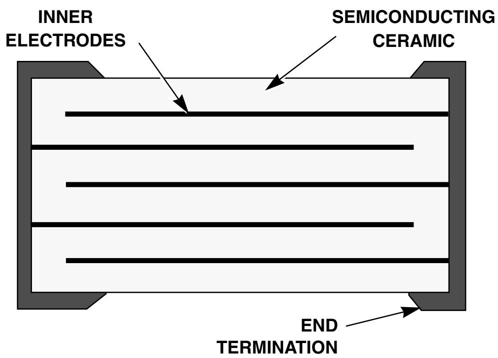

FIGURE 3. INTERNAL CONSTRUCTION OF THE HARRIS MULTILAYER TRANSIENT VOLTAGE SUPPRESSOR

A further advantage of this type of construction is that the breakdown voltage of the device is dependent on the thickness between the electrode layers (dielectric thickness) and not the overall thickness of the device.

These suppressors are often much smaller in size than the components they are designed to protect. The present size offerings are 0603, 0805, 1206, 1210, 1812 and 2220, with voltage ranges form $3.5V_{DC}$ to $120V_{DC}$. Its robust construction makes it ideally suitable to endure the thermal stresses involved in the soldering, assembling and manufacturing steps involved in surface mount technology. As the device is inherently passivated by the fired ceramic material, it will not support combustion and is thus immune to any risk of flammability which may be present in the plastic or epoxy molded parts used in industry standard packages.

Substrates

There are a wide choice of substrate materials available for use as printed circuit boards in a surface mount application. The main factors which determine the choice of material to use are:

1. Electrical Performance
2. Size and Weight Limitations
3. Thermal Characteristics
4. Mechanical Characteristics
5. Cost

When choosing a substrate material, the coefficient of thermal expansion of a Littelfuse surface mountable suppressor of $6ppm/^oC$ is an important consideration. Non-organic materials (ceramic based substrates), like aluminum or beryllia, which have coefficients of thermal expansion of $5\text{-}7ppm^oC$, are a good match for the CH and ML series devices. Table 1 outlines some of the other materials used, and also their more important properties pertinent to surface mounting.

While the choice of substrate material should take note of the coefficient of expansion of the devices. This may not be the determining factor in whether a device can be used or not. Obviously the environment of the finished circuit board will determine what level of temperature cycling will occur. It is this which will dictate the criticality of the match between device and PCB. Currently for most applications, both the CH and ML series use FR4 boards without issue.

Fluxes

Fluxes are used for the chemical cleaning of the substrate surface. They will completely remove any surface oxides, and will prevent re-oxidation. They contain active ingredients such as solvents for removing soils and greases. Nonactivated fluxes (“R” type) are relatively effective in reducing oxides of copper or palladium/silver metallizations and are recommended for use with the Littelfuse surface mount range.

Mildly activated fluxes (“RMA” type) have natural and synthetic resins, which reduce oxides to metal or soluble salts. These “RMA” fluxes are generally not conductive nor corrosive at room temperature and are the most commonly used in the mounting of electronic components.

The “RA” type (fully activated) fluxes are corrosive, difficult to remove, and can lead to circuit failures and other problems. Other non-resin fluxes depend on organic acids to reduce oxides. They are also corrosive after soldering and also can damage sensitive components. Water soluble types in particular must be thoroughly cleaned from the assembly.

Environmental concerns, and the associated legislation, has led to a growing interest in fluxes with residues that can be removed with water or water and detergents (semi-aqueous cleaning). Many RMA fluxes can be converted to water soluble forms by adding saponifiers. There are detergents and semi-aqueous cleaning apparatus available that effectively remove most RMA type fluxes. Semi-aqueous cleaning also tends to be less expensive than solvent cleaning in operations where large amounts of cleaning are needed.

TABLE 1. SUBSTRATE MATERIAL PROPERTIES

SUBSTRATE STRUCTURE	MATERIAL PROPERTIES		
	GLASS TRANSITION TEMPERATURE (^oC)	XY COEFFICIENT OF THERMAL EXPANSION ($ppm/^oC$)	THERMAL CONDUCTIVITY (W/M^oC)
Epoxy Fiberglass-FR4	125	14-18	0.16
Polyamide Fiberglass	250	12-16	0.35
Epoxy Aramid Fiber	125	6-8	0.12
Fiber/Teflon Laminates	75	20	0.26
Aluminium-Beryillia (Ceramic)	Not Available	5-7	21.0

For the Harris Suppression Products range of surface mount varistors, nonactivated “R” type fluxes such as Alpha 100 or equivalent are recommended.

Land Pad Patterns

Land pad size and patterns are one of the most important aspects of surface mounting. They influence thermal, humidity, power and vibration cycling test results. Minimal changes (even as small as 0.005 inches) in the land pad pattern have proven to make substantial differences in reliability.

This design/reliability relationship has been shown to exist for all types of designs such as in J lead, quadpacks, chip resistors, capacitors and small outline integrated circuit (SOIC) packages. Recommended land pad dimensions are provided for some surface mounted devices along with formulae which can be applied to different size varistors. Figure 4 gives recommended land patterns for the direct mount ML and CH series devices.

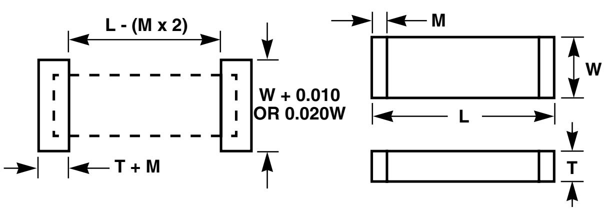

FIGURE 4. FORMULA FOR SURFACE MOUNTABLE VARISTOR FOOTPRINTS

TABLE 2. RECOMMENDED MOUNTING PAD OUTLINE

SUPPRESSOR FAMILY	DIMENSION		
	T + M	L-(M X 2)	0.020W (W + 0.010)
5 X 8 CH Series	2.21 (0.087)	5.79 (0.228)	5.50 (0.216)
0603 ML/MLE Series	1.12 (0.044)	0.56 (0.02)	1.62 (0.064)
0805 ML/MLE Series	1.48 (0.058)	0.69 (0.027)	2.13 (0.084)
1206 ML/MLE Series	1.65 (0.065)	1.85 (0.073)	2.62 (0.103)
1210 ML/AUML Series	1.85 (0.073)	1.85 (0.073)	3.73 (0.147)
1812 AUML Series	1.85 (0.073)	3.20 (0.126)	4.36 (0.172)
2220 AUML Series	1.84 (0.073)	4.29 (0.169)	6.19 (0.240)

Solder Materials and Soldering Temperatures

No varistor should be held longer than necessary at an elevated temperature. The termination materials used in both the CH and ML series devices are enhanced silver based materials. These materials are sensitive to exposure time and peak temperature conditions during the soldering process (Figure 5). The enhanced silver formulation contains either platinum, palladium or a mixture of both, which have the benefit of significantly reducing any leaching effects during soldering. To further ensure that there is no leeching of the silver electrode on the varistor, solders with at least 2% silver content are recommended (62 Sn / 36 Pb / 2 Ag). Examples of silver bearing solders and their associated melting temperatures are as follows:

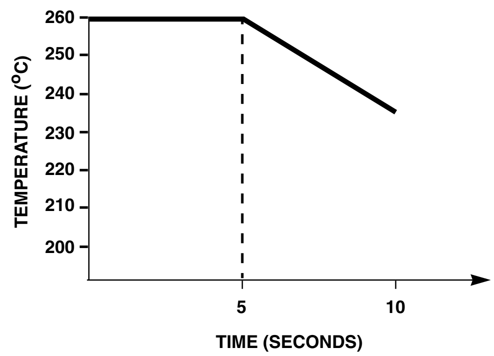

FIGURE 5. RECOMMENDED MAXIMUM TIME AND SOLDER TEMPERATURE RELATIONSHIP OF LITTELFUSE MOVs

TABLE 3. SILVER BEARING SOLDERS (ALPHA METALS)

ALLOY	MELTING TEMPERATURE	
	^{o}F	^{o}C
62 Sn / 36 Pb / 2 Ag	355	179
96.5 Sn / 3.5 Ag	430	221
95 Sn / 5 Ag	430-473	221-245
20 Sn / 88 Pb / 2 Ag	514-576	268-302
5 Sn / 92.5 Pb / 2.5 Ag	536	280

Soldering Methods

There are a number of different soldering techniques used in the surface mount process. The most common soldering processes are infrared reflow, vapor phase reflow and wave soldering.

With the Littelfuse surface mount range, the solder paste recommended is a 62/36/2 silver solder. While this configuration is best, other silver solder pastes can also be used. In all soldering applications, the time at peak temperature should be kept to a minimum. Any temperature steps employed in the solder process must, in broad terms, not exceed 70^{o}C to 80^{o}C. In the preheat stage of the reflow process, care should be taken to ensure that the chip is not subjected to a thermal gradient of greater than 4 degrees per second; the ideal gradient being 2 degrees per second. For optimum soldering, preheating to within 100 degrees of the peak soldering temperature is recommended; with a short dwell at the preheat temperature to help minimize the possibility of thermal shock. The dwell time at this preheat temperature should be for a time greater than 10T^2 seconds, where T is the chip thickness in millimeters. Once the soldering process has been completed, it is still necessary to protect against further effects of thermal shocks. One possible cause of thermal shock at the post solder stage is when the hot printed circuit boards are removed from the solder and immediately subjected to cleaning solvents at room temperature. To avoid this thermal shock affect, the boards must first be allowed to cool to less than 50^{o}C prior to cleaning.

Two different resistance to solder heat tests are routinely performed by Harris Suppression Products to simulate any possible effects that the high temperatures of the solder processes may have on the surface mount chip. These tests consist of the complete immersion of the chip in to a solder bath at 260^{o}C for 5 seconds and also in to a solder bath at 220^{o}C for 10 seconds. These soldering conditions were chosen to replicate the peak temperatures expected in a typical wave soldering operation and a typical reflow operation.

Reflow Soldering

There are two major reflow soldering techniques used in SMT today:

1. InfraRed (IR) Reflow
2. Vapor Phase Reflow

The only difference between these two methods is the process of applying heat to melt the solder. In each of these methods precise amounts of solder paste are applied to the circuit board at points where the component terminals will be located. Screen or stencil printing, allowing simultaneous application of paste on all required points, is the most commonly used method for applying solder for a reflow process. Components are then placed in the solder paste. The solder pastes are a viscous mixture of spherical solder powder, thixotropic vehicle, flux and in some cases, flux activators.

During the reflow process, the completed assembly is heated to cause the flux to activate, then heated further, causing the solder to melt and bond the components to the board. As reflow occurs, components whose terminations displace more weight, in solder, than the components weight will float in the molten solder. Surface tension forces work toward establishing the smallest possible surface area for the molten solder. Solder surface area is minimized when the component termination is in the center of the land pad and the solder forms an even fillet up the end termination. Provided the boards pads are properly designed and good wetting occurs, solder surface tension works to center component terminations on the boards connection pads. This centering action is directly proportional to the solder surface tension. Therefore, it is often advantageous to engineer reflow processes to achieve the highest possible solder surface tension, in direct contrast to the desire of minimizing surface tension in wave soldering.

In designing a reflow temperature profile, it is important that the temperature be raised at least 20^{o}C above the melting or liquidus temperature to ensure complete solder melting, flux activation, joint formation and the avoidance of cold melts. The time the parts are held above the melting point must belong enough to alloy the alloy to wet, to become homogenous and to level, but not enough to cause leaching of solder, metallization or flux charring.

A fast heating rate may not always be advantageous. The parts or components may act as heat sinks, decreasing the rate of rise. If the coefficients of expansion of the substrate and components are too diverse or if the application of heat is uneven, fast breaking or cooling rates may result in poor solder joints or board strengths and loss of electrical conductivity. As stated previously, thermal shock can also damage components. Very rapid heating may evaporate low boiling point organic solvents in the flux so quickly that it causes solder spattering or displacement of devices. If this occurs, removal of these solvents before reflow may be required. A slower heating rate can have similar beneficial effects.

InfraRed (IR) Reflow

InfraRed (IR) reflow is the method used for the reflowing of solder paste by the medium of a focused or unfocused infrared light. Its primary advantage is its ability to heat very localized areas.

The IR process consists of a conveyor belt passing through a tunnel, with the substrate to be soldered sitting on the belt. The tunnel consists of three main zones; a non-focused preheat, a focused reflow area and a cooling area. The unfocused infrared areas generally use two or more emitter zones, thereby providing a wide range of heating profiles for solder reflow. As the assembly passes through the oven on the belt, the time/temperature profile is controlled by the speed of the belt, the energy levels of the infrared sources, the distance of the substrate from the emitters and the absorptive qualities of the components on the assembly.

The peak temperature of the infrared soldering operation should not exceed 220^{o}C. The rate of temperature rise from the ambient condition to the peak temperature must be carefully controlled. It is recommended that no individual temperature step is greater than 80^{o}C. A preheat dwell at approximately 150^{o}C for 60 seconds will help to alleviate potential stresses resulting from sudden temperature changes. The temperature ramp up rate from the ambient condition to the peak temperature should not exceed 4^{o}C per second; the ideal gradient being 2^{o}C per second. The dwell time that the chip encounters at the peak temperature should not exceed 10 seconds. Any longer exposure to the peak temperature may result in deterioration of the device protection properties. Cooling of the substrate assembly after solder reflow is complete should be by natural cooling and not by forced air.

The advantages of IR Reflow are its ease of setup and that double sided substrates can easily be assembled. Its biggest disadvantage is that temperature control is indirect and is dependent on the IR absorption characteristics of the component and substrate materials.

On emergence from the solder chamber, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the IR reflow soldering process is as Table 4 and Figure 6.

TABLE 4. RECOMMENDED TEMPERATURE PROFILE FOR IR REFLOW SOLDER PROCESS

INFRARED (IR) REFLOW	
TEMPERATURE (^oC)	TIME (SECONDS)
25-60	60
60-120	60
120-155	30
155-155	60
155-220	60
220-220	10
220-50	60

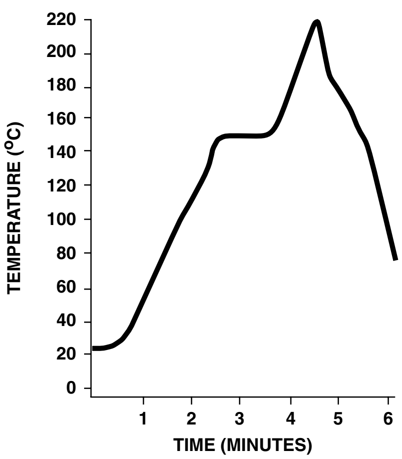

FIGURE 6. TYPICAL TEMPERATURE PROFILE

Vapor Phase Reflow

Vapor phase reflow soldering involves exposing the assembly and joints to be soldered to a vapor atmosphere of an inert heated solvent. The solvent is vaporized by heating coils or a molten alloy, in the sump or bath. Heat is released and transferred to the assembly where the vapor comes in contact with the colder parts of the substrate and then condenses. In this process all cold areas are heated evenly and no areas can be heated higher than the boiling point of the solvent, thus preventing charring of the flux. This method gives a very rapid and even heating affect. Further advantages of vapor phase soldering is the excellent control of temperature and that the soldering operation is performed in an inert atmosphere.

The liquids used in this process are relatively expensive and so, to overcome this a secondary less expensive solvent is often used. This solvent has a boiling temperature below 50^oC. Assemblies are passed through the secondary vapor and into the primary vapor. The rate of flow through the vapors is determined by the mass of the substrate. As in the case of all soldering operations, the time the components sit at the peak temperature should be kept to a minimum. The dwell time is a function of the circuit board mass but should be kept to a minimum.

On emergence from the solder system, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the vapor phase soldering process is as Table 5 and Figure 7.

TABLE 5. RECOMMENDED TEMPERATURE PROFILE FOR VAPOR PHASE REFLOW PROCESS

VAPOR PHASE REFLOW	
TEMPERATURE (^oC)	TIME (SECONDS)
25-90	8
90-150	13
150-222	3
222-222	10
222-80	7
80-25	10

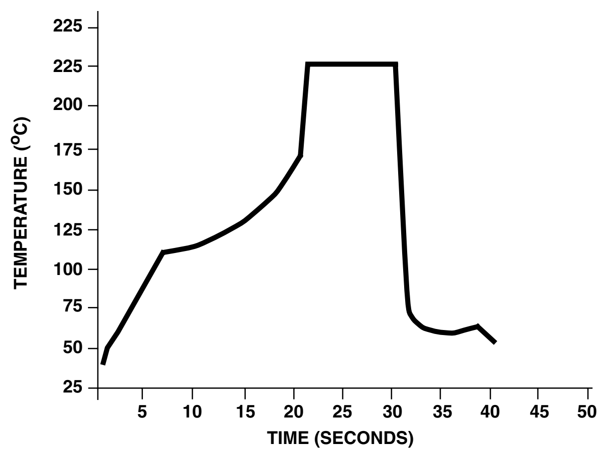

FIGURE 7. TYPICAL TEMPERATURE PROFILE

Wave Solder

This technique, while primarily used for soldering thru-hole or leaded devices inserted into printed circuit boards, has also been successfully adapted to accommodate a hybrid technology where leaded, inserted components and adhesive bonded surface mount components populate the same circuit board.

The components to be soldered are first bonded to the substrate by means of a temporary adhesive. The board is then fluxed, preheated and dipped or dragged through two waves of solder. The preheating stage serves many functions. It evaporates most of the flux solvent, increases the activity of the flux and accelerates the solder wetting. It also reduces the magnitude of the temperature change experienced by the substrate and components.

The first wave in the solder process is a high velocity turbulent wave that deposits large quantities of solder on all wettable surfaces it contacts. This turbulent wave is aimed at solving one of the two problems inherent in wave soldering surface mount components, a defect called voiding (i.e. skipped areas). One disadvantage of the high velocity turbulent wave is that it gives rise to a second defect known as bridging, where the excess solder thrown at the board by the turbulent wave spans between adjacent pads or circuit elements thus creating unwanted interconnects and shorts.

The second, smooth wave accomplishes a clean up operation, melting and removing any bridges created by the turbulent wave. The smooth wave also subjects all previous soldered and wetted surfaces to a sufficiently high temperature to ensure good solder bonding to the circuit and component metallizations.

In wave soldering, it is important that the solder have low surface tension to improve its surface wetting characteristics. Therefore, the molten solder bath is maintained at temperatures above its liquid point.

On emergence from the solder wave, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the wave soldering process is as Table 6:

TABLE 6. RECOMMENDED TEMPERATURE PROFILE FOR WAVE SOLDER PROCESS

WAVE SOLDER	
TEMPERATURE (^{o}C)	**TIME (SECONDS)**
25-125	60
125-180	60
180-260	60
260-260	5
260-180	60
180-80	60
80-25	60

Termination Options

Littelfuse offers two types of electrode termination finish for the Multilayer product series:

1. Silver/Platinum (standard)
2. Silver/Palladium (optional)

Cleaning Methods and Cleaning Fluids

The objective of the cleaning process is to remove any contamination from the board, which may affect the chemical, physical or electrical performance of the circuit in its working environment.

There are a wide variety of cleaning processes which can be used, including aqueous based, solvent based or a mixture of both, tailored to meet specific applications. After the soldering of surface mount components there is less residue to remove than in conventional through hole soldering. The cleaning process selected must be capable of removing any contaminants from beneath the surface mount assemblies. Optimum cleaning is achieved by avoiding undue delays between the cleaning and soldering operations; by a minimum substrate to component clearance of 0.15mm and by avoiding the high temperatures at which oxidation occurs.

Littelfuse recommends 1, 1, 1 trichloroethane solvent in an ultrasonic bath, with a cleaning time of between two and five minutes. Other solvents which may be better suited to a particular application and can also be used may include one or more of the following:

TABLE 7. CLEANING FLUIDS

Water	Acetone
Isopropyl Alcohol	Fluorocarbon 113
Fluorocarbon 113 Alcohol Blend	N-Butyl
1, 1, 1 Trichloroethane Alcohol Blend	Trichloroethane
Toluene	Methane

Solder Defects

Non-Wetting:

This defect is caused by the formation of oxides on the termination of the components. The end termination has been exposed to the molten solder material but the solder has not adhered to the surface; base metal remains exposed. The accepted criterion is that no more than 5% of the terminated area should remain exposed after an immersion of 5 seconds in a static solder bath at 220^{O}C, using a nonactive flux.

Leaching:

This is the dissolving of the chip termination into the molten solder. It commences at the chip corners, where metal coverage is at a minimum. The result of leaching is a weaker solder joint. The termination on the Littelfuse surface mount suppressors consist of a precious metal alloy which increases the leach resistance capability of the component. Leach resistance defined as the immersion time at which a specified proportion of the termination material is visibly lost, under a given set of soldering conditions.

De-Wetting:

This condition results when the molten solder has coated the termination and then receded, leaving irregularly shaped mounds of solder separated by areas covered with a thin solder film. The base metal is not exposed.

References

For Littelfuse documents available on the web, see http://www.littelfuse.com/

[1] “Transient Voltage Suppression Devices”, Harris Suppression Products DB450.

[2] CANE SMT 2588, Syfer Technology Limited, UK.