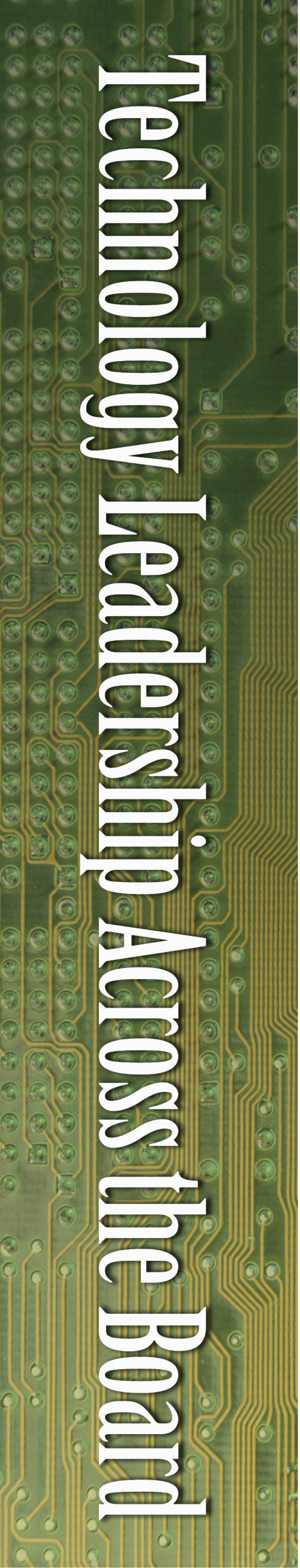

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Ultrathin Discrete Capacitors for Emerging Embedded Technology

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ABSTRACT

Passive components can represent as much as 70% of PCB footprint in today's electronic systems. The development of a suitable technology whereby integrated passive components are embedded into the PCB body has been one of the key trends in downsizing for more than a decade. Latest achievements have allowed the implementation of this 'embedding technology' into pre-production and even mass production. The next step requires the involvement of the complete supply chain, including traditional passive component manufacturers. This paper will present the state of the art in the development of ultrathin discrete capacitor technology and discuss the challenges of overcoming mechanical, electrical and thermo-mechanical issues specific to the embedding processes. Reliability and component life considerations will be also shown and discussed.

INTRODUCTION

Miniaturization is one of the key design issues faced by a wide range of latest electronic devices. Designers are challenged to use every single square millimeter of the PCB. Until relatively recently only one side of the PCB could be populated by electronic components, than technology was improved and both sides could be used. The embedding of electronic components inside the PCB is a next logical step and direction in miniaturization evolution.

To take just one example, today there are from 10-50 resistors and 60-150 capacitors commonly used in cell phones which could be considered suitable for embedding based on the current stage of the technology. This fact is causing some manufacturers to seriously consider including embedded passives on their technology roadmaps. Passive embedded technology would not have become worth investigating for the mass volume consumer market unless there is a potential for cost saving. Together with offering increased functionality or the same functionality in a smaller size, there is also the potential to reduce the cost of final encapsulation as the placing of components between substrates should provide adequate protection against ambient conditions.

Both passive and active electronic components can be integrated using embedding techniques. Although the component split in cost on most boards will be 67% active, 24% interconnect and connectors and just 9% for passives, by components count passives account for at least 70% with actives making up 20% and interconnect just 10% (data source: Decision). So, while passive components are obviously significantly cheaper than actives they take up around 70% of board space, focusing the main embedding effort onto passive components. Ceramic capacitors have already been practically demonstrated at sub-miniature 0201 and even 01005 sizes. Although the price of these tiny components is low, users especially in the consumer sector should pay attention to the total cost of the system as the pick-and-place costs can be three times higher than the component cost when placement time, yield and rework is considered.

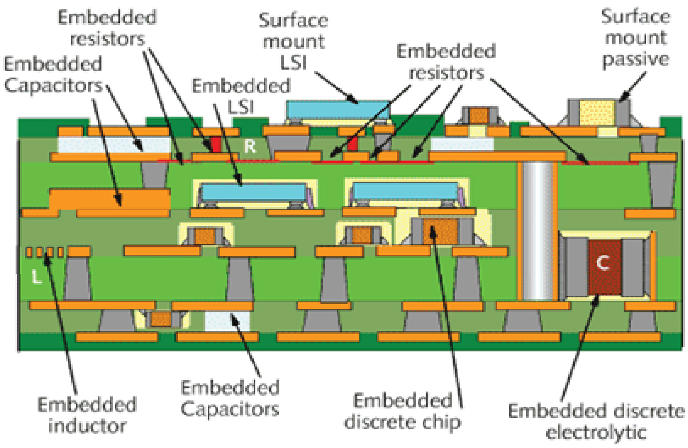

Fig.1: Embedding Technologies inside a PCB

EMBEDDING TECHNOLOGY

General Description

Embedding electronic components has been described in publications either as a technique which creates the components directly during PCB manufacturing or as a process where currently existing, specially designed or common electronic components inserted into the inner layers of a board.

Figure 2 shows general description of the embedding technology in three steps.

1. Component assembly – individual components are placed onto pre-prepared copper foil in a specific position according to the design.

2. Component packaging – Step by step treated foils of substrate are placed around and on top of the devices followed by another copper foil. Under pressure and temperature the sandwich is laminated together to create the core of the new PCB.

3. PCB manufacturing – The third step is structuring the copper tracks and layers into required circuits and the construction of the PCB - achieved using existing procedures.

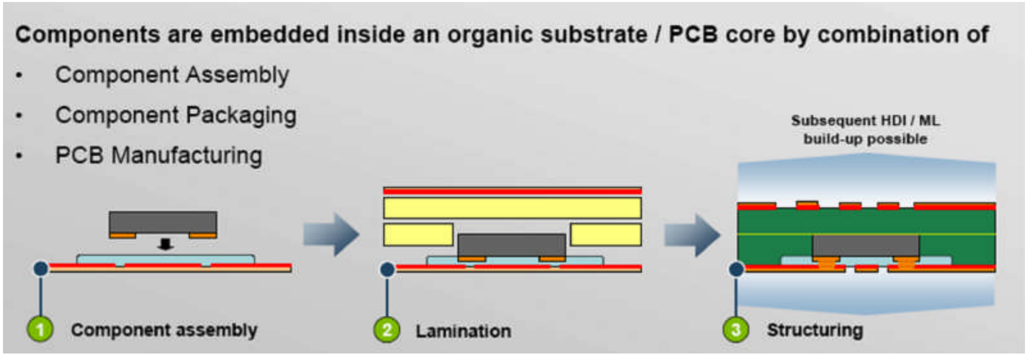

Fig.2: The three stages of embedding technology

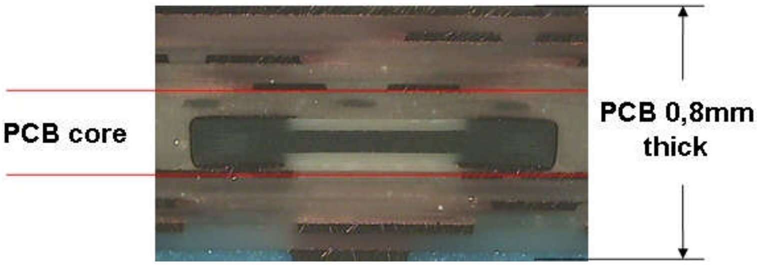

Fig.3: Cross- sectioning of embedded ceramic capacitor in the substrate

Advantages/Challenges

As well as the main advantage, which was already mentioned, namely, the efficient usage of the inner space of the PCBs which leads to a reduction in overall size or an ability to include additional features in the same foot print, passive embedding technology offers other benefits such as improving certain physical and electrical properties.

- Improvement of electrical parameters (for example shorter distance between components)

- Increased reliability (components encapsulated in a protective environment)
- Better resistance to mechanical stress
- Improved thermal properties (better heat sinking)
- Design copy protection.

However, challenges include:

- 3D design skills required
- Supply chain of both, embedding technologies and passives is still limited

<u>Capacitors for Embedding Technology – General Requirements</u>

Thickness of the components:

Apart from the normal parameters driven by the functionality of passive components, for embedded technology applications, thickness is the most important overall dimension. Despite of the fact that PCB manufacturers have the ability to embed different thickness of devices, there seems to be a move now by the cell phone makers - *the biggest drivers of embedding technology today* - to have 150µm accepted as the universal embedded component height - this ‘standard’ is expected to solidify as the technology is accepted into mass cell phone production.

Various component manufacturers have adopted different approaches to address the overall thickness issue as standard termination techniques are not suitable because of the:

- Component thickness itself; and the
- Variability of the thickness of the termination.

Take, as an example, the standard 0402 ceramic capacitor. There was 10pcs measured from one random lot (no lot to lot variation is considered). Every unit was measured at three points see Figure 4.

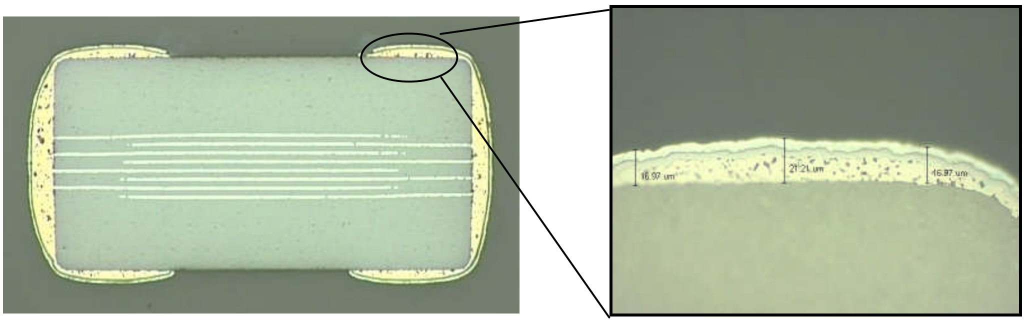

Fig.4: Example of the standard 0402 component with detail to measured points.

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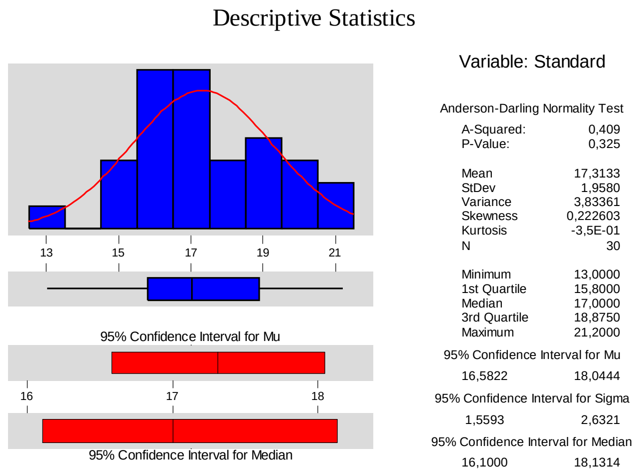

Fig.5: Analysis of the measured components

It is obvious that the standard MLCC termination technique which typically uses a termination thickness of 17µm with a standard deviation 1.95µm is inappropriate for the embedded technology. The figure needs to be multiplied by two for both sides of the ceramic capacitor. Hence the termination thickness would have a significant influence on the overall thickness requirement of 150µm.

Other Dimensions

Overall dimensions apart from the thickness are considered to play only the same role as with standard SMD technology: most likely there is still plenty of room inside of the PCB. (This factor may become more influential later as embedding technology matures in mass production.) The maximum component thickness of 0.15mm and 0402 size may become the favourite passive component dimension at present stage of the manufacturers' technological capabilities.

Final treatment of the terminations

Surface finishing may also need some modification to fit better into the construction technology used for the inner structure of the PCB. Standard MLCC technology typically uses a Ni/Sn layer to guarantee a suitable solderability performance for SMD technology. However, for embedding technology processing a copper layer termination surface finish is better option.

Component features

With respect to technology availability and the capacitors most commonly-used in the mobile industry, there are two values which are of greatest interest to PCB suppliers at the moment. These are 10nF and 100nF devices with a rated voltage of 6.3V, class II (X5R). It is obvious that ceramic capacitors, despite their thickness which causes several manufacturing challenges, must still fulfill standard device functionality. For example:

- Electrical properties
    - Capacitance, Dissipation Factor
    - Insulation resistance

    - Temperature characteristic.
    - ESR, ESL
- Reliability: embedded components may need to meet different requirements than standard SMD parts mounted on top of the PCB.
- Mechanical properties
    - Resistance to mechanical stress (Flexure)
    - Thermal Cycling
    - Stress Test – test which has been introduced specially for embedding applications. This test is designed to simulate stress during the pick and place operation during PCB population where the force to which the parts are exposed to is usually in range of several Newtons.

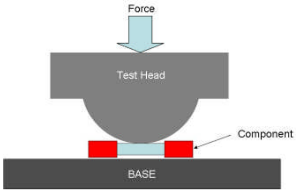

Fig.6: Drawing of the stress test procedure

Manufacturing and Verification of MLCC Embedded Capacitors

Terminations

AVX has implemented a new FCT (Fine Copper Technology) technique to overcome the issues concerning termination thickness and its variations. FCT technology allows the creation a very thin and flat termination layer. Copper layer terminations have also been proved to be the most suitable and appropriate for the embedding technology processes.

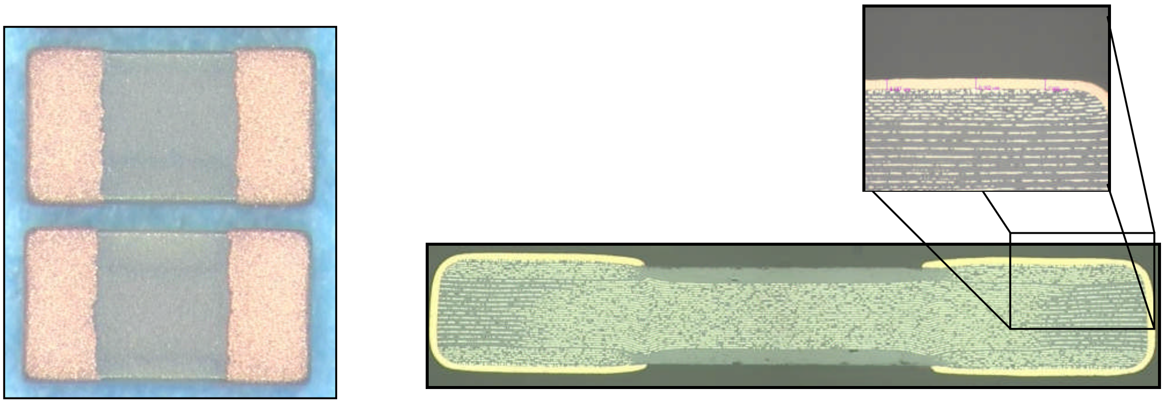

Fig.7: Example of the FCT termination + position of the measuring points

In the same way as measurement was performed on standard MLCC SMD parts (Fig.4), ceramic capacitors with terminations created by the FCT process were analyzed - see Fig. 8. The average thickness of FCT is 8.3µm with a standard deviation 0.5µm. This is a significant improvement over the 17µm +/- 1.95µm achieved by conventional processes on standard MLCC capacitors designed for standard SMD usage.

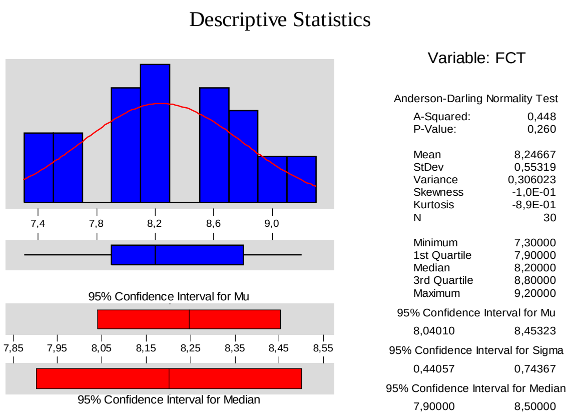

Fig.8: Thickness analysis of the FCT termination

Performance of the Manufactured Embedded Capacitor

The following section summarizes the performance of embedded MLCC 0402 capacitors that have been developed and introduced to the pre-production phase. The data is taken from the case study of an ultrathin X5R MLCC embedded technology capacitor of case size 0402, capacitance 10nF, and voltage 6.3V, with a maximum thickness of 0.15mm. The data compares the parameters measured before and after embedding.

<u>Electrical Characteristics</u>

Capacitance and Dissipation Factor – see Figs. 9 and 10. Very similar values capacitance values and tolerances have been achieved for loose unit and embedded parts. The loose components are showing 10.8nF capacitance with standard deviation of 0.23nF. After the embedding process, values of 10.95nF with standard deviation 0.26nF were measured. Similar results have been achieved with DF see Fig.11

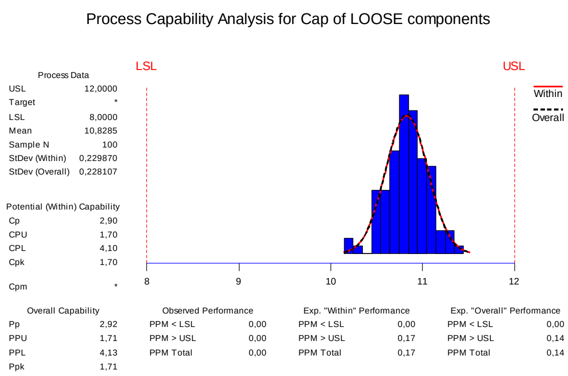

Fig.9: Capacitance capability of the loose parts

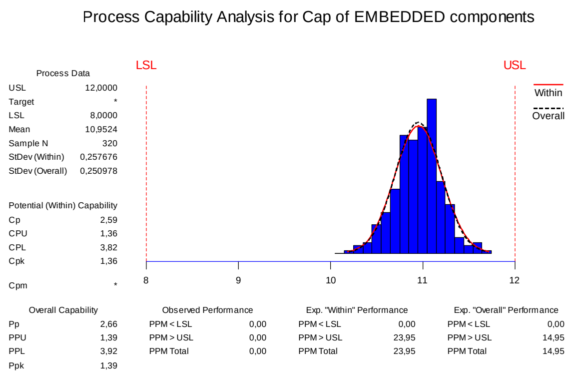

Fig.10: Capability of the embedded units

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One-way ANOVA: DF versus Mount
Analysis of Variance for DF
Source     DF        SS        MS        F        P
Mount       1     0,313     0,313     1,56    0,212
Error     418    83,757     0,200
Total     419    84,069
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -+---------+---------+---------+-----
Embedded  320    5,1468    0,4505   (-------*-------)
Loose     100    5,2109    0,4384       (-------------*-------------)
                                   -+---------+---------+---------+-----
Pooled StDev =   0,4476           5,100     5,160     5,220     5,280
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Fig.11: Analysis of DF variance among the units before and after embedding.

Overview of Key Parameters:

	Conditions	Limits	Units	Loose	Embedded
Cap	1kHz @ 1Vrms	10nF±10%	nF	**10.83**	**10.95**
Df	1kHz @ 1Vrms	<12.5%	%	**5.21**	**5.14**
IR	Soak 60s @ RV	>100GΩ	GΩ	**121**	**125**
ESR	1KHz - 10MHz	N/A	mΩ	**131**	**N/A**
ESL	1KHz - 10MHz	N/A	pH	**178**	**N/A**
Hermo Cycle	-55-125°C 1000cycles	>100GΩ	Pass/Fail	**Pass**	**Pass**
Temp Coef.	-55-85°C meas. 1kHz @ 1Vrms	±25% cap.	% change	**+2; -9%**	**+2; -9%**
Life	1000h @ 1,5xRV and 125°C	IR > 10GΩ	Pass/Fail	**Pass**	**Pass**
THB	96h @ 1xRV and 85RH/85°C	IR > 10GΩ	Pass/Fail	**Pass**	**Pass**
Flexure	9mm pitch, 2mm bend	2mm	Pass/Fail	**Pass**	**Pass**

Table 1: Overview of selected parameters used for testing embedding MLCC capacitors

Future Directions

Initial development work has been performed on the most popular capacitance ranges: 10 and 100nF, 6.3V devices in 0402 case sizes that have been released by year 2010. It is obvious that future requirements will be to embed larger capacitance, smaller case sizes and wider application voltages. The next challenges will be to implement a 1μF, 6.3V capacitor, preferably in the 0402 case size. This may provide the motivation and impetus for other capacitor technologies - namely tantalum - to enter into the embedded passive technology world.

An intermediate step in embedding tantalum technology has been presented by AVX's tantalum division detailing the concept of a 0.6mm thick capacitor with modified terminations. The application in this case is a 'through hole' where the capacitor body is placed in a square hole in the PCB and soldered on top of the PCB – see Fig. 12. Actually this might not be considered as 'true' embedded solution as it presents a way to insert a high capacitance 47μF 6.3V device just within the thickness of PCB. New techniques concerning the manufacture of 0.15mm tantalum capacitors are now under investigation by tantalum capacitor makers and powder suppliers.

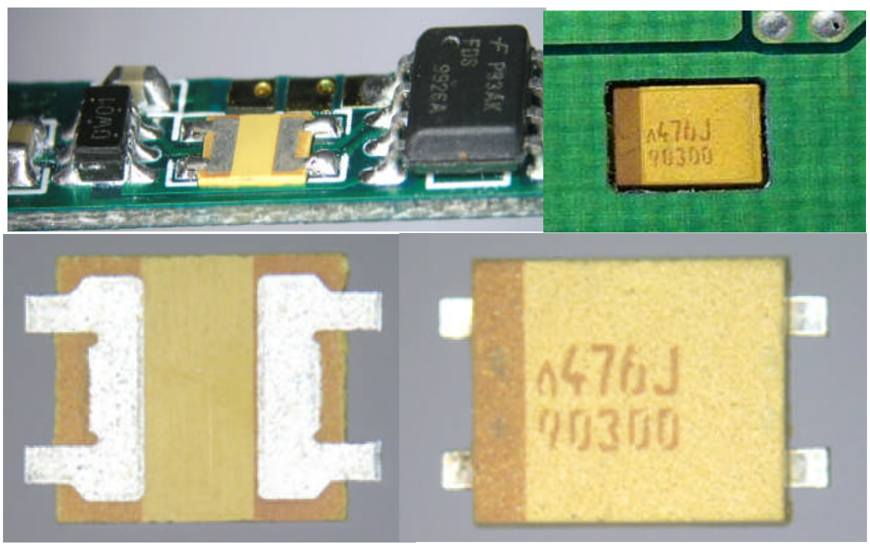

Fig.12: 'Tthrough PCB'47μF 6.3V tantalum capacitor

SUMMARY & CONCLUSION

The data presented in this paper has demonstrated that embedding and connecting ceramic capacitors within the electronic circuit is a robust and reliable process. Based on the latest advancements and developments we can state that ceramic capacitor technology is ready to address the demands of the new challenging production technology - embedding. 100nF 6.3V MLCC capacitor with 0.15mm thickness have been already introduced to mass manufacturing as an example of the latest addition to the family of embedded MLCC capacitors. Some other capacitor technologies, such as tantalum, are also progressing well in this respect.

Embedded technologies have been under development and test for many years. Now, however, as of the writing this paper, embedded ceramic capacitor technology has finally started the important transition to mass manufacturing. We are entering a new age in the way of parts are assembled. Embedding has already proved its potential for cost saving in some areas, and also has the ability to add new functionality and features to end devices. This is especially true in consumer electronics where smaller, higher function and more reliable products have emerged using the technology. It may still be some while - even a decade - before embedding technology will start to dominate the assembly processing. However manufactures' attitudes are changing and moving towards acceptance of the technology, which will result in modifications within the supply chain such that 'embedded-ready' components are widely available.

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