Leadframe Hybrid Technology in Low Power DC-DC Converters

Abstract

Newport Components Limited have developed a technique for manufacturing hybrid DC-DC converters using a leadframe substrate for component assembly and a transfer moulding method to package the completed DC-DC converter. The technique allows high volume production of low power hybrid isolated DC-DC converters to be realised using silicon chip assembly methods to produce a final hybrid component that looks and s handled by the customer as a standard integrated circuit. This paper presents the techniques used and production challenges that have been overcome to produce a truly integrated hybrid circuit. The methods have also enabled a further increase in miniaturisation of the DC-DC converter device providing a product with the highest power density available in its product group.

Background

The low power hybrid DC-DC converter was first introduced by Newport Components Limited (NCL) in 1985 as a single component solution to the DC-DC converter circuit function. The first devices were all through hole packages (single-in-line, SIL and dual-in-line, DIL) offering the primary advantage of reduced board space and component count over a discrete solution.

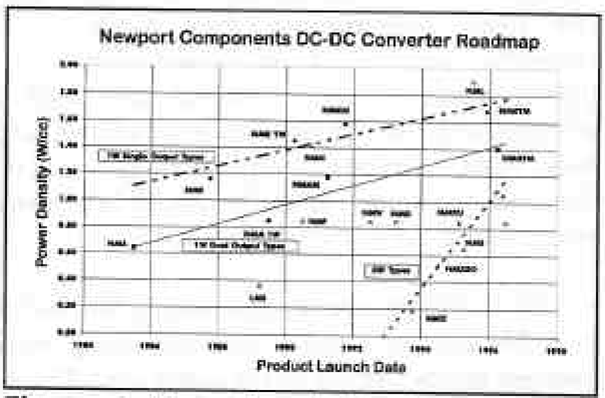

Figure 1: Power Density Roadmap

The principle goal for low power board level DC-DC converters has been miniaturisation (under 5W, PCB mounting devices). Miniaturisation is considered the main reason for using an integrated DC-DC converter module rather than producing a discrete solution. The progress of miniaturisation is usually translated in terms of power density (Watts per cubic centimetre, W/cc) and the aim of all DC-DC converter designers is to maximise the available power from the smallest device possible.

Low loss semiconductors and high performance ferrite cores help improve the efficiency of the DC-DC converter circuit and consequently increase the power density. However there is a limit to the physical size that the electrical components can be produced with these low loss features. Eventually the optimisation of the electronics alone limits the miniaturisation and the designer must look at other aspects of the hybrid DC-DC construction if miniaturisation is to continue.

Methods of assembly and packaging of hybrid circuits have in general evolved relatively slowly. The thermal construction of the DC-DC converter becomes a major factor once the limit of optimisation of internal electrical components is reached. The hybrid substrate was originally of resin fibre board (FR4), this has been replaced with a ceramic material (Al_2O_3) due to the improved thermal conductivity of ceramic. Standard hybrid interconnect on ceramic is produced using silver loaded inks, for a power component this does not have sufficient current handling capability and electroplated copper on ceramic techniques were employed.

Further miniaturisation can be achieved by removing the packaging of the individual components. Bare die and wire bonding is used where maximum packing density is required, this enables a further increase in power density due to both increased component density and better thermal performance of direct bonding of silicon onto a ceramic substrate.

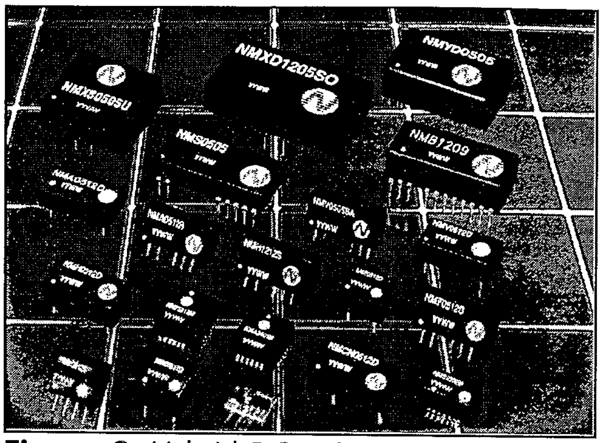

Figure 2: Hybrid DC-DC Converters

Encapsulation of early hybrid products featured a dip-coated epoxy finish. This has been replaced in the DC-DC converter product development with higher quality casing material and high thermal conductivity polyurethane resin encapsulant. As higher conductivity encapsulants have been made available these have been used, however, the packaging method has remained relatively constant through the past 8 years with only minor improvements available in power density due to encapsulant performance increases.

In 1991 NCL introduced the worlds first surface mount (SM) DC-DC converter, encased in a SM pinned header and lid, using standard hybrid assembly techniques on an internal copper-on-ceramic substrate. The success of this product, and huge demand it generated, soon proved the existing manufacturing techniques were too restrictive on throughput to satisfy the market. A programme to develop a more automated technique that would provide volume production was initiated and by 1994 this programme completed development. In early 1995 production of the first truly integrated hybrid DC-DC converters was introduced.

Surface Mount Hybrid DC-DC Converter Manufacture

The first SM products introduced by NCL helped to develop the necessary production techniques for the manufacture of a hybrid component that the customer can handle like any SM integrated circuit (IC). The product had to be designed not only for the production processes available at NCL, but also had to be compatible with the production techniques used by the customers.

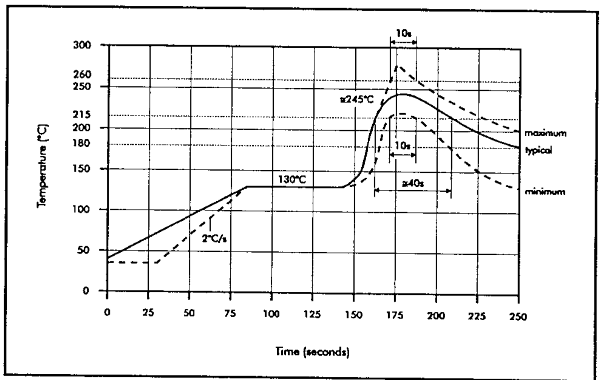

Figure 3: CECC00805 IR Reflow Profile

One of the first production challenges was to develop a process that would allow customers to use standard CECC00802 reflow profiles with a hybrid circuit, without damaging the internal construction. The maximum peak reflow temperature a component lead can observe using the CECC recommended profiles is 280°C with an infra-red (IR) reflow oven, this can mean a temperature at the DC-DC converter component surface in excess of 300°C. Obviously standard 220°C solders and thermoplastic casing materials were not adequate for these high temperature excursions. A high temperature reflow oven was developed by NCL, and later further developed by our reflow oven supplier, to produce an environment where a 301°C solder could be reflowed at NCL without damage to the active and passive components within the DC-DC converter circuit. Initially a vapour phase technique was used and later changed to an in-line nitrogen atmosphere convection system to increase throughput and for increased automation.

The casing was manufactured from thermoset plastics, hence would not deform under high reflow temperatures, the device also had a thermal compound encapsulant filling. The encapsulant helped dissipate the surface heat during customer reflow processes without raising the internal substrate temperature beyond the maximum the internal components could tolerate. In the end circuit application the thermal encapsulant also helped dissipate any internally generated heat.

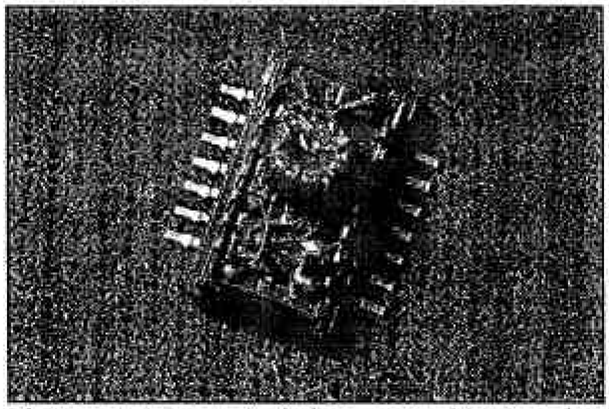

Figure 4: Ceramic Substrate in SM Header

Requirement of New Hybrid Techniques

Initially the requirement for a new method of manufacturing the SM DC-DC converter was for a higher throughput of devices to meet the market demand. Consequently a more automated production method was desired with fewer production processes if possible. It was also beneficial to achieve a further increase in miniaturisation as this is always the desire of DC-DC converter designers, however, this was secondary to the requirement for increased production output.

It was realised very early that two of the most labour and time intensive operations were the assembly of the ceramic header into the SM case and the whole encapsulation process. The new technique would have to significantly improve on both of these NCL production issues without compromising the customer handling properties of the existing part (e.g. automatic placement compatible, CECC00802 reflow profile tolerant).

Leadframe Technology

The main advantage of using a leadframe technique to the production throughput of DC-DC converters is that there is no separate assembly of a substrate into a header, the leadframe forms the footprint itself. Consequently one process, header assembly, is removed and the cost of producing a SM footprint is reduced. Additional care has to be exercised in the handling of the leadframe to ensure co-planarity, however, this would now be totally in the control of the production line operator and not the supplier of the SM header. Consequently better production control over the whole assembly operation could be exercised.

The challenges in using this technique were to produce a leadframe that would have the electrical pattern of the DC-DC converter circuit, was rigid enough to hold the components, could be used with standard automatic pick and place equipment and flexible enough to withstand the lead forming required for the final package footprint. The leadframe base material was also to have a finishing process to allow the part to be processed by the customer on a standard SM production line, hence lead finish would have to be compatible with other IC's and commercially available components. Finally the thermal characteristics of the leadframe must be adequate to handle the power dissipated by the device without causing thermal stress to the internal components.

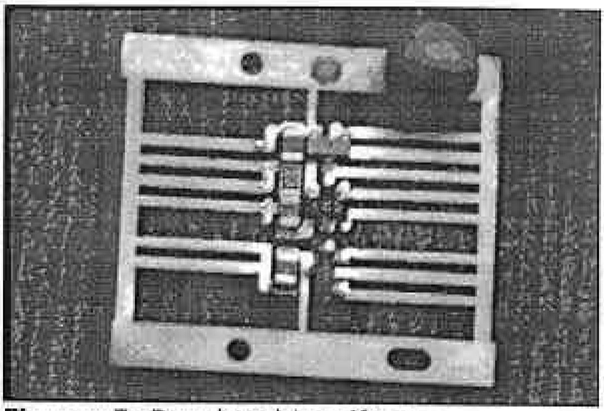

Figure 5: Populated Leadframe

Several materials were evaluated which were in common use in silicon leadframe assemblies and eventually a copper base material was selected. This provided adequate mechanical strength during placement, with sufficient additional strengthening patterning, and offers very good malleability for lead forming during the production process. The copper base material also provides excellent electrical conduction properties, important for a power circuit, and the thicker tracking compared to the substrate version improved thermal dissipation from the active components. Adhesion of the lead-tin (Pb:Sn) lead finish is excellent to clean copper so that customer solder adhesion is guaranteed and meets CECC00802 solderability standards.

Having an in-house lead finish, rather than using a plated leadframe, allows NCL to offer other lead finishes to those customers who have a specific requirement. This allows for the design of new and custom products for use in environments that a standard IC lead finished may not be capable of withstanding.

Encapsulation

The main production bottleneck with final package encapsulation is the lack of automation. The SM header case is composed of two separate parts (a pinned base and lid) which are filled with the thermal encapsulant. The assembly of these parts significantly increases the encapsulation process time. Improvements in the level of automation were required to improve throughput, any reduction in the

Figure 6: Transfer Moulding Press

number of assembly operations would also reduce production time, hence increase throughput.

It was believed that using a solid moulding over the circuit could be used to improve the automation and throughput (similar to the techniques used in IC encapsulation). The main problem was the effect of a solid moulding on the ferrite transformer as hard setting plastic materials were known to effect the magnetic properties of ferrite due to mechanical constriction (magnetostriction). Additionally this would be a new process to NCL requiring a large investment in equipment, training and process development, with no guarantee of success. Initial results from the moulding equipment supplier and discussions with our silicon vendors convinced us of the feasibility. The solution to the transformer encapsulation was initially to use a two mould process and a coated transformer to prevent magnetostriction of the ferrite.

The material was selected to offer similar thermal properties to the existing discrete power component packaging used on the internal components, hence matching their thermal expansion coefficients and heat transfer characteristics. The use of thermoset plastic had been determined from experience with existing SM DC-DC converters due to its lack of deformation under high temperature processes. A solid moulded body would also give a suitable surface for automatic placement machinery to register and pick the component for placement, this maintained the ease of handling the customer had already become accustomed to with SM components.

Tooling

Often overlooked and certainly less glamorous than the leadframe or moulding processes themselves, tooling has been an area of significant investment which was required to enable the leadframe technique to operate effectively in volume production. The tools required were for the bending, cropping and lead forming of the leadframe as it progressed through the production process. The end result is an assembly method that provides a better transformer attachment internally with reduced assembly time as well as a lead form that offers high co-planarity (to IEC 191-6) as a final stage in processing. The lead forming as the last production process ensures that no further handling is required which could cause the leads to be out of specification.

Finished Product

The finished product meets all our expectations and even exceeds some in its case finish and styling. As an integrated solution the market acceptance has been even better than with the original SM hybrid DC-DC converters introduced in 1991. Already volumes are taking off rapidly and the devices availability in a tape and reel format has added to its appeal to both design and production engineers.

Product Name	NME	NMA
Output Type	Single	Dual
Process Changes	Power Density (W/cc)	
FR4 PCB	1.16	0.64
Ceramic Substrate	1.45	0.85
Surface Mount	1.58	1.18
Lead Frame	1.68	1.40

Figure 7: Power Density Improvements

Although not a primary objective at the commencement of the process development, the new leadframe and transfer moulding process has provided further advances in miniaturisation. The 1W board level DC-DC converter products that the process has so far been applied to have seen increases in power density of between 6% and 18% (figure 7). Thus the process has enabled NCL to remain at the forefront of board level power products offering the smallest devices available in their power class with both single and dual output rails.

As a production process, the leadframe and transfer moulding of hybrid DC-DC converters has been successfully installed in Milton Keynes and additional manufacturing plant successfully transferred to our UK manufacturing site in Workington, Cumbria. Further process developments are in hand to increase automation in the handling processes and hopefully move towards an in-line moulding system similar to the automatic placement lines currently employed at NCL.

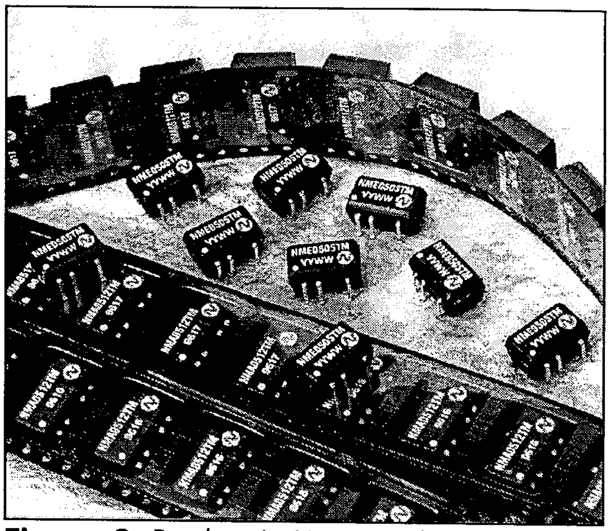

Figure 8: Product in Tape and Reel Format

Further products are to be transferred to the leadframe and transfer moulding process within the next few years. It is expected that most of the existing DC-DC converter catalogue will be available in this SM format by the end of the century. The customer will no longer be able to claim that the only non SM parts in their system are the connectors and DC-DC converters.

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