Direct Thermal Exchange (DTE) As a Solution to Thermally Conductive Dielectric Limitations in Thermal Management PCB Designs

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***Abstract* -- Direct Thermal Exchange (DTE) is a new PCB construction methodology that has been developed to achieve highly-efficient heat removal or thermal dissipation. This paper presents Direct Thermal Exchange (DTE) as a technology solution to the current limitations of thermally conductive dielectric when used in thermal management (heat dissipative) designs for high-power circuits (LED, Wireless, Microwave) in Printed Circuit Board (PCB) designs.**

I. DIRECT THERMAL EXCHANGE (DTE)

As the name implies, DTE is a 'direct' thermal transfer method when high amounts of thermal energy must be removed quickly and consistently from a heat-generating device. DTE was developed primarily to address thermal problems posed by the development of high power LEDs with demanding thermal performance, although it can be used in many other applications.

DTE design creates a direct thermal path conduction capability and reduces LED junction temperature far more efficiently when compare to traditional FR- 4 PCB, MCPCB or Aluminum PCB constructs. Lower junction temperature extends LED life, improves LED brightness (higher lumens per LED), improves product reliability and minimizes overall dollar-per-lumen operating cost. DTE is an important enabling technology for LED arrays especially those intended for outdoor lighting and emergency vehicles, where heat dissipation is an ever-increasing concern as the technology of high-power LEDs advances.

II. THE NEED TO MINIMIZE LED JUNCTION TEMPERATURE

LED lighting provides both promise and challenges for virtually every electric lighting application currently served by earlier illumination technologies such as incandescent and fluorescent lighting. But the drawback for LED lighting, in concentrated arrays or in high-power applications, is the dissipation of heat. This heat must be conducted away from the die to the underlying circuit board and heat sinks. Allowing the die to overheat directly affects both short-term and long-term LED performance. LED system manufacturers are addressing this challenge by seeking out improved heat sink designs, high efficiency circuit boards, high thermal conductivity enclosures and other advanced thermal design techniques. Whenever possible, through built-in thermal management schemes incorporated into the PCB design, adequate cooling should be achieved through conduction through the board rather than cooling schemes such as fans that add to the complexity of the overall PCB assembly. LEDs radiate *minimal* heat into the space around the source. Consequently, *all* of the heat generated by the LEDs must be conducted away from the source by physical means, i.e., a conduction path. If the heat generated by

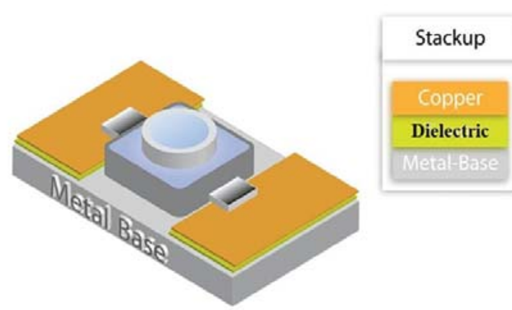

***Figure 1**. Stackup scheme for Direct Thermal Exchance (DTE) with a high-brightness LED.*

the LEDs is not conducted away, and excessive heat builds up in the LED, the LED cannot function properly and can be permanently damaged. The light emitted by it can change to an unacceptable color, and its working life can be seriously curtailed. Thus, designers and specifiers should ensure that the PCB material and type selected for the LED application offers the least thermal resistance in order to avoid LED 'thermal runaway'.

The DTE PCB approach eliminates use of a dielectric material completely from a conduction thermal path, allowing direct thermal exchange.

III. DTE: NO THERMALLY-INSULATIVE LAYER

Metal Core and standard FR-4 with thermal vias are commonly used circuit board materials to dissipate heat from medium- to high power LEDs. In the instance of Metal Core PCBs and MCPCB (often known as aluminum or copper layer), the key to thermal performance lies in its dielectric layer. Even though thermally-conductive dielectric offers better thermal performance when compared to standard dielectric material, it is still the weakest link in the thermal conduction path, since it cannot conduct heat more efficiently than through direct thermal exchange. The DTE PCB approach overcomes this limitation and eliminates use of a dielectric material completely from the thermal path.

Currently, the best performance that can be obtained from dielectric conductivity is 4 watts per square meter kelvin [4 W / (m2 · K)]. Metal, however (metal core layer) dissipates thermal energy at 300 W / (m2 · K). Thus, the case for DTE becomes immediately apparent, because DTE achieves thermal dissipation rates much closer to the Metal rate, with variations based on component type, PCB metal layer thickness, surface are, and other factors dependent upon individual applications, but always well beyond the capabilities of dielectric conductive materials.

Even though the dielectric material may be thermally conductive, it still has a thermally insulative component to it, and this increases with the thickness of the layer. Thus, if the dielectric layer can be eliminated, greater thermal transfer efficiency can result, since the dielectric layer is performing, effectively, as a thermal bottleneck.

To facilitate thermal transfer, solder paste is printed and reflowed on the PCB at the location of the LED on the Z-axis. The LED housing is metal; but its electrical connections (on either side) are protected by continuation of the dielectric layer at the perimeter of the LED (or other component) location, as shown in the accompanying **Figure 1**. The application of solder paste and reflowing it is a function of the assembly process, not the PCB fabrication process, per se.

No PCB design changes are necessary; every component and connection on the PCB are unaffected. However, the role of the PCB fabricator, when DTE is to be implemented, is to mask/remove the dielectric in the areas of the DTE target components so that there is no dielectric material between the body of the component, often metal, and the metal core layers of the PCB.

Solder paste is printed (4 – 6 mil depending on the individual application) and when reflowed, it is not critical if the liquid solder does not wet to the body of the component; what is important is that it provides a solid thermally conductive path between the LED and the metal core of the PCB, rather than an air space (no matter how minimal) which would have an insulative effect. It is important to remember that the paste printing and reflow are achieved during the assembly process and that establishing the LED's electrical connections (leads) in a reflow step can be achieved concurrent with the reflow of the base printed solder beneath the LED. Any type of solder paste can be used (for example, the same material being used to make the electrical connections, e.g., lead-free or SnPb for hi-rel applications); the process window is actually quite wide. The component is actually electrically isolated; its contact with the metal core is entirely thermal.

A panel etch-out process is used by the PCB fabricator prior to the assembly process to ensure that the level of the component is matched to make sure that the DTE pad is in line with the circuitry level needed to make robust electronic (leads) solder connections during mass reflow (assembly).

IV. DTE STACKUP

In simplest terms, a DTE stackup consists of three layers: copper (top), then a dielectric layer beneath the copper, and then the metal base; however, as can be seen from the accompanying diagram, a direct conductive thermal path exists between the LED and the metal base.

DTE characteristics and benefits are summarized as follows:

- 135 to 385W/m.K heat transfer rate through Direct Thermal Exchange conduction;
- Lower LED Junction Temperature for longer LED life;
- More lumens with fewer LEDs;
- Direct replacement for MCPCB;
- Minimum or Zero design change required from current MCPCB designs;

Any base metal thickness can be used, and any typical dielectric can be used, including FR-4, epoxy, and polyimide. Since no PCB design change is required, DTE can be implemented simply, quickly, and at minimum cost and without undue complications.

V. CONCLUSION

DTE is a ‘direct’ thermal transfer method effective in removing high amounts of thermal energy quickly and consistently from a heat-generating device. DTE was developed primarily to address thermal problems posed by the development of high power LEDs with demanding thermal performance, although it can be used in many other applications. DTE has been proven to be an effective solution to thermal management issues.

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