

# Thermal Design made Simple with LM43603 and LM46002

Marc Davis-Marsh

## ABSTRACT

This Application Report will walk through the thermal design of power supplies using the LM43603 and LM46002. In the process we will cover common tips and approximations to speed up your design.

### Contents

1	Board Layout for Good Thermal Design .....	1
2	Power Dissipation Hand Calculation .....	2
3	Power Dissipation on WEBENCH® .....	2
4	Comparison to Thermal Camera Images and WEBENCH® .....	5
5	Figures .....	7
6	References .....	7

### List of Figures

1	Efficiency Curve .....	2
2	$\theta_{JA}$ vs Copper Area; 2oz Copper on Outer Layers and 1oz Copper on Inner Layers .....	5
3	Layout Recommendations .....	7

## 1 Board Layout for Good Thermal Design

Thermal design doesn't need to be arduous. Let's walk through a quick thermal design for the LM43603 or LM46002 using WEBENCH® and some rules of thumb. Then we will look at measurement results and see the type of accuracy we can expect.

### CAUTION

**Use of these tips will speed up your board layout for good thermal performance, but you should still take due diligence to ensure that your design is working to your specifications.**

First off, in any thermal design, you need to calculate how much power is being dissipated by your device. You can do this one of two ways. You can calculate it by hand or you can use the online design tool WEBENCH®

Secondly you need to determine the thermal environment to which the part is going to be subjected. If you have an enclosure with access to open air and the device is allowed to run hot this would correspond to an ambient temperature ( $T_A$ ) of your open air and a maximum junction temperature ( $T_J$ ) for the device of 125°C. This would allow you to calculate a thermal impedance from the junction to ambient air ( $\theta_{JA}$ ).

$$\theta_{JA} \leq \frac{T_{Jmax} - T_{amb}}{Pd(IC)} \quad (1)$$

And finally, you need to lay out the board with enough copper or external heat-sinking to achieve the thermal impedance calculated above. The rest of this application note will walk you through the process.

## 2 Power Dissipation Hand Calculation

The most common method to calculate the power dissipation is to look in the datasheet curves and find the efficiency for your operating condition. With the efficiency information you can back calculate the system power dissipation. You would then subtract out the inductor power loss or external diode power losses to find the IC power loss. Here is an example: Your input voltage is 24 V. Your output Voltage is 5 V. Your peak load current is 3 A. You decide to run at 500 kHz to trade off physical component size and efficiency. You look up the datasheet in the product folder at the TI website. <http://www.ti.com/product/LM43603>

Then you find the efficiency curve in which you are interested.

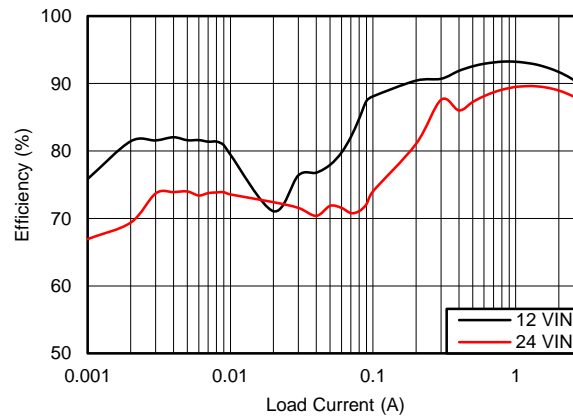


Figure 1. Efficiency Curve

The efficiency from the graph is  $\approx 86\%$ .

The DCR of the inductor (33 m $\Omega$ ) can be found in the Bill of Materials on page 10 of the LM43603EVM User's Guide. The power dissipation  $P_D$  can then be estimated by

$$P_D (IC) \sim P_D (System) - P_D (Inductor)$$

$$P_D (IC) \sim (V_{out} \times I_{out}) \times [(1/\text{Efficiency})-1] - ((1.1 \times I_{out})^2 \times DCR)$$

$$P_D (IC) \sim (5V \times 3A) \times [(1/0.86)-1] - (1.1 \times (3A)^2 \times 0.033 \Omega)$$

$$P_D \sim 2.08W$$

## 3 Power Dissipation on WEBENCH®

The easiest method to calculate the power dissipation is to run the design in WEBENCH® and read the IC power dissipation from the table. Here is an example: Your parameters are the same as before:  $V_{in} = 24$  V,  $V_{out} = 5$  V,  $I_{out} = 3$  A,  $f_{SW} = 500$  kHz. Go to WEBENCH® either on the TI.COM main page or the product folder at the TI website. <http://www.ti.com/product/LM43603>

On the right hand side enter the parameters into the WEBENCH® interface. Enter an ambient temperature of 27°C. Click "Open Design".

**WEBENCH® LM43603**

	Min	Max	Range
Vin	24	24	V 3.50 – 36.00V
Vout		5	V 1.00 – 28.00V
Iout		3	A ≤ 3A
Ambient Temp		30	°C ≤ 125°C

<b>Footprint</b>	<b>BOM Cost</b>	<b>Efficiency</b>
388	\$4.27	81%

**Open Design**

Once into the WEBENCH® interface the design, several versions of the design will have been created and WEBENCH® will show the version it feels has been optimized for size and efficiency. To force WEBENCH® to use the frequency we want, the lower left corner has a check box for user preferred frequency. Check this box, enter your preferred frequency and update the design.

The screenshot shows the WEBENCH Optimizer interface with several key sections:

- Optimization Tuning:** A gauge showing a balance between BOM Cost (\$3.74), Footprint (317), and Efficiency (86%).
- Charts:** A graph of Efficiency (%) vs. Iout(A) showing a peak efficiency of approximately 92% at 0.8A.
- Schematic:** A circuit diagram of the LM43603 converter.
- WEBENCH® Optimizer:** A summary of design goals and a Power Dissipation Chart.
- Operating Values:** A table of key parameters including Vin=24.0V, Iout=5.0, and IC PD=1.96W.
- Bill of Materials:** A table listing components like capacitors, inductors, and resistors with their values and quantities.
- Your Complete Design:** A sidebar with options for design documentation, CAD file export, and sharing.

If you look at the operating values at the bottom left, or click on the Op Vals tab for a close up, you will see a variety of values that WEBENCH® has computed to complete the design. The Value IC PD is the power dissipation of the IC. According to WEBENCH® the power dissipation is 1.96W.

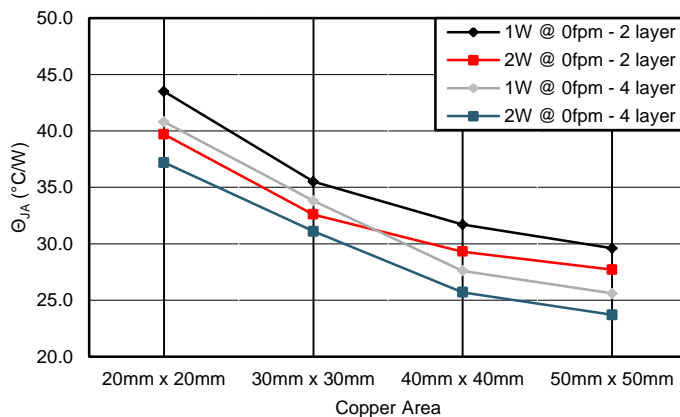
What other information can we glean from WEBENCH®

If you look further into the Operating values you can see that WEBENCH® has calculated and estimated the IC temperature based upon the  $\theta_{JA}$  simulated on a JEDEC board. The IC  $\theta_{JA}$  WEBENCH® used was 38.9°C/W and the calculated IC temperature calculated was IC  $T_J = 102^\circ\text{C}$ .

If the IC temperature is low enough for your design, then try to mimic a JEDEC layout. A JEDEC layout has an unbroken 3 by 3 inch (76.2 x 76.2 mm) ground plane on the 2nd layer that connects to the exposed pad of the IC with thermal vias. The number of thermal vias should be appropriate to the size of the exposed pad. Typically the thermal vias are 8 mils (200 um) to avoid solder wicking and spaced near a 1 mm grid. With the LM43603, with an exposed, pad of 2.4 x 3.2mm, you can easily fit nine thermal vias.

If the JEDEC thermal impedance is too high for your application, remember that the JEDEC design uses no additional copper heat-sinking on the top or bottom layers to spread the heat away from the exposed pad. While this is very realistic for a high density design, the board design is not always so constrained. There is often room on either the top or bottom layer for additional copper to spread the heat away from the part.

In the datasheet for the LM43603 there is a curve that shows the area of copper used for heat-sinking versus the thermal impedance. Remember when using this curve that it is assuming that either 2 layers or 4 layers all contain the copper heat sinking area shown on the x-axis of the curve.



**Figure 2.  $\theta_{JA}$  vs Copper Area;  
2oz Copper on Outer Layers and 1oz Copper on Inner Layers**

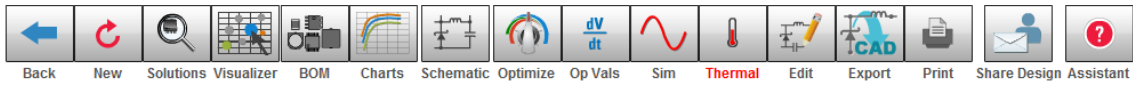
You can see from the graph that the thermal impedance can be reduced from the JEDEC value of 38.9C/W to around 24°C/W if we pay attention to the thermal design. A general rule of thumb is that the amount of copper needed on the top and bottom of a two layer design is

$$\text{Board Area (cm}^2\text{)} \geq 15.29 \frac{\text{cm}^2}{\text{W}} \times P_D$$

For the 2.09W in our design this leads to a recommended minimum copper for heat-sinking of 56 x 56mm. If we look at our curve this corresponds to  $\theta_{JA} \approx 27^\circ\text{C/W}$ , and an IC temperature of 86°C.

#### 4 Comparison to Thermal Camera Images and WEBENCH®

Now the test. Can I use WEBENCH® or the datasheet to predict the temperature of a running board? If we go back to the WEBENCH® interface and click on the thermal tab, we can start a thermal simulation of the Evaluation board for the LM43603. The simulation parameters are on the left hand side. Enter an input voltage of 24 V, and output current of 3 amps. The temperature of my lab is 27°C. And the copper weight is 2 oz. Click the “Create a New Simulation” button. This will start a pop-up window with a list of simulations. When yours is finished click on the results and you will see a simulation similar to the one below. The simulation predicted the IC temperature to be 67°C using the evaluation board. Now what if we use the  $\theta_{JA}$  from the curve. The Evaluation board size is 90 x 70 mm. The area is roughly equivalent to 79 x 79 square mm. If we extrapolate from the curves in Figure 2 this leads to a  $\theta_{JA}$  of roughly 20°C/W. This leads to an estimated IC temperature of  $20 \times 2.08 + 27 = 68.6^\circ\text{C}$ . With an Evaluation board under a thermal imaging camera you can see that the case temperature was measured to be 64.2°C. The die temperature of the part would be a few degrees hotter than the case. Using  $\psi_{JT}$  of 0.7W/C from the datasheet, we can calculate that the die temperature was  $0.7\text{C/W} \times 2.08 + 64.2 = 65.6^\circ\text{C}$ . So with this data we can see that both methods were very accurate. With these tools, and parts with great thermal layouts, a thermal design for the LM43603 or LM46002 can be extremely simple. For more information on thermal layouts, please see [SNVA419 Thermal Design by Insight, Not Hindsight](#).



WEBTHERM™ SIMULATIONS

All WebTHERM™ Simulations Current Simulation

Simulation ID: 1  
 Name This Simulation:  
**Simulation for Design #241**  
 Comments:  
 Created by SMS7.1

**Thermal Sim Parameters**

Operating Condition  
 Vin: 24 Iout: 3

Ambient Temperature  
 On Bottom: 30 °C On Top: 30 °C

Board Condition  
 Copper Weight: 0.5 OZ.(0.01778 mm) Board Orientation: Component Side Up

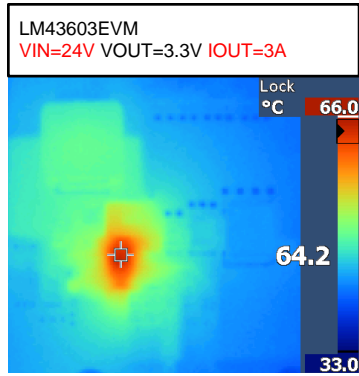
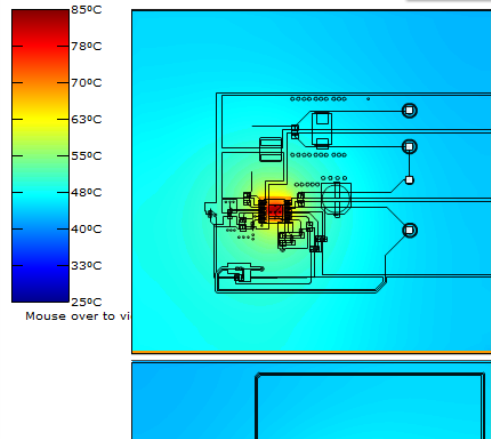
Air Flow  
 Direction: [Diagram] Velocity: Use [Fan] [None] [0] [LFM] [LMM]

Edge Temperatures  
 Edge 1  Insulated OR NaN °C

Create a New Simulation  
 Save Thermal Image  
 Zoom Out Zoom In  
 Show Thermal Image  
 Show Outline

Temperature Bar Scaling  
 Min Colorbar Temp: 25  
 Max Colorbar Temp: 85  
 Change Reset

Operating Temperatures				
Layer	Max T	PDiss.	Manufacturer	Part Number



5 Figures

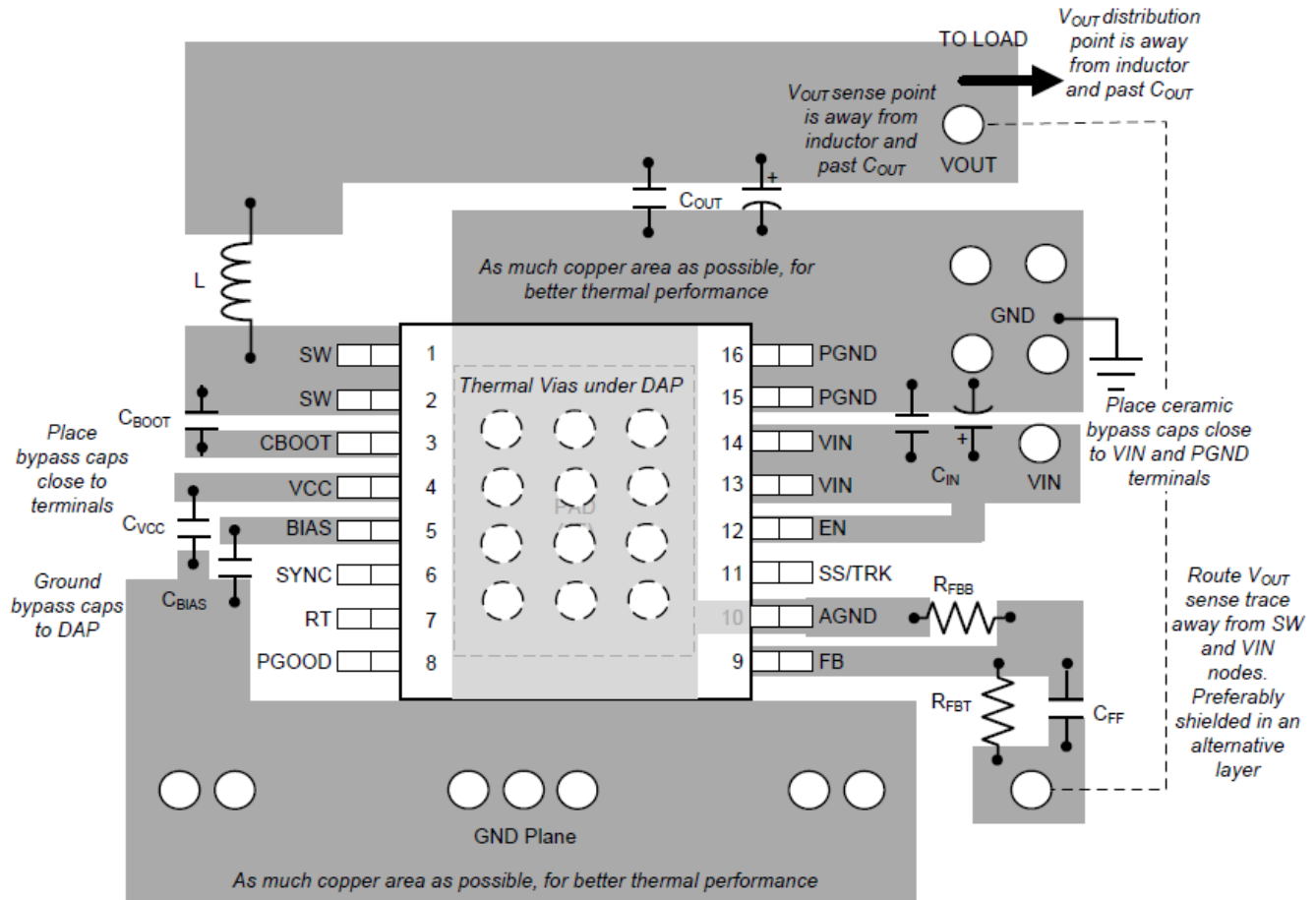


Figure 3. Layout Recommendations

6 References

1. AN-2020 Thermal Design By Insight, Not Hindsight (SNVA419)
2. LM43603 SIMPLE SWITCHER® 3.5 V to 36 V 3-A Synchronous Step-Down Voltage Converter (SNVSA09)

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Applications Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

### TI E2E Community

[e2e.ti.com](http://e2e.ti.com)