

Ease Power Supply Design with Design Tools

by

**Jeff Perry, Senior Manager, WEBENCH Design Tools
National Semiconductor Corp.**

As most electrical system design engineers have experienced, power supply design is often left until the last minute. With a deadline looming and the boss looking over one's shoulder, an engineer is in a rush to get something fast. Faced with the complexity of implementing a DC to DC switching power supply design under these circumstances, designers can be put under stress and possibly make the wrong decisions.

But it doesn't have to be this way. The latest power supply design tools provided by IC manufacturers, such as National Semiconductor's WEBENCH® Design Environment, provide an efficient alternative to the traditional trial and error approach to design. A user can do virtual testing and optimization before constructing a prototype thereby reducing or eliminating costly and time consuming design iterations. The result is a higher quality and more robust design which is tailored to the designer's needs.

Design tools are also useful for more experienced power supply design engineers. With access to a database of thousands of components provided by a good design tool, engineers can visualize tradeoffs using real part numbers with accompanying parametric, price and footprint information, a task which might otherwise involve extensive research.

A power supply design environment should be easy to use and provide an end to end on-line enabled design and prototyping process. The design flow can be broken out as follows:

- 1) User enters design parameters and selects from a listing of recommended topologies/regulators.
- 2) Software calculates passive components and power supply characteristics.
- 3) User optimizes the design using graphs to visualize tradeoffs.
- 4) Designer conducts real time electrical simulation to view dynamic circuit behavior and further refine the design.
- 5) User performs thermal simulation to identify and correct heat problems.
- 6) Software facilitates easy on line ordering of samples, demo boards and custom prototype kits with overnight processing.

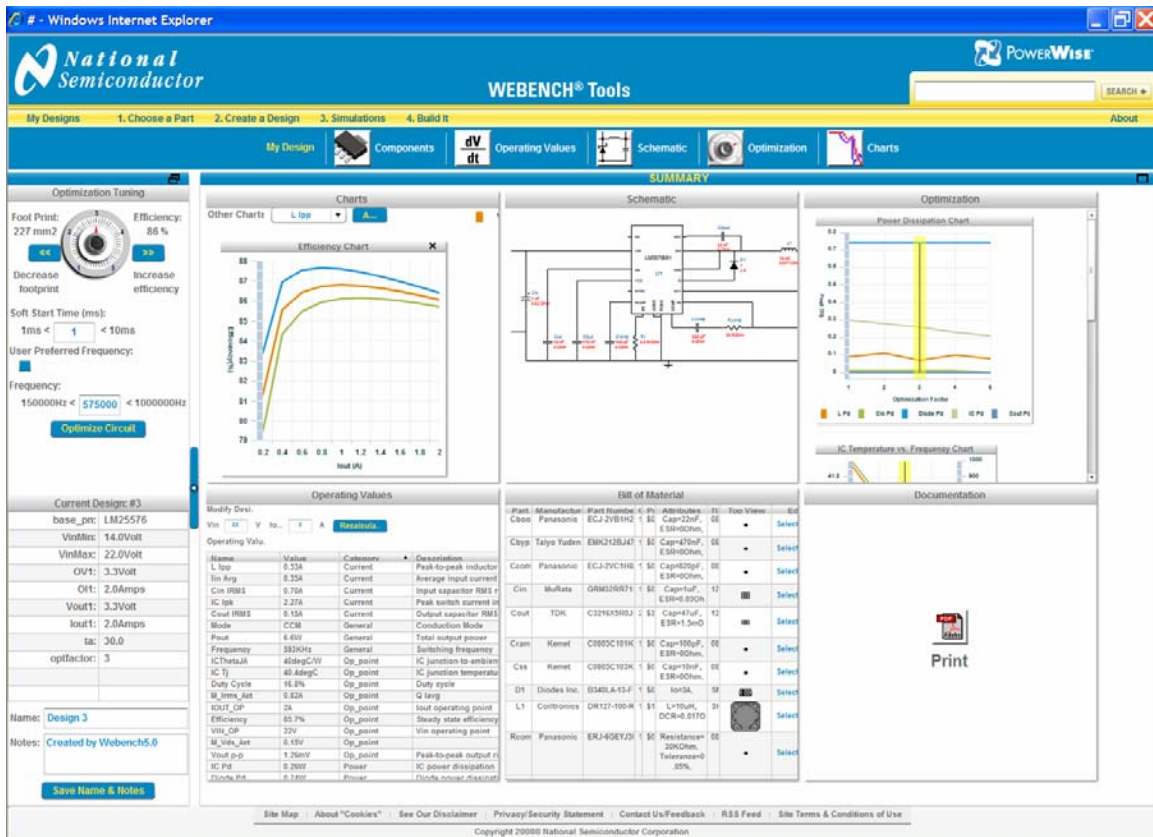


Figure 1: National Semiconductor's WEBENCH Power Supply Design Tool

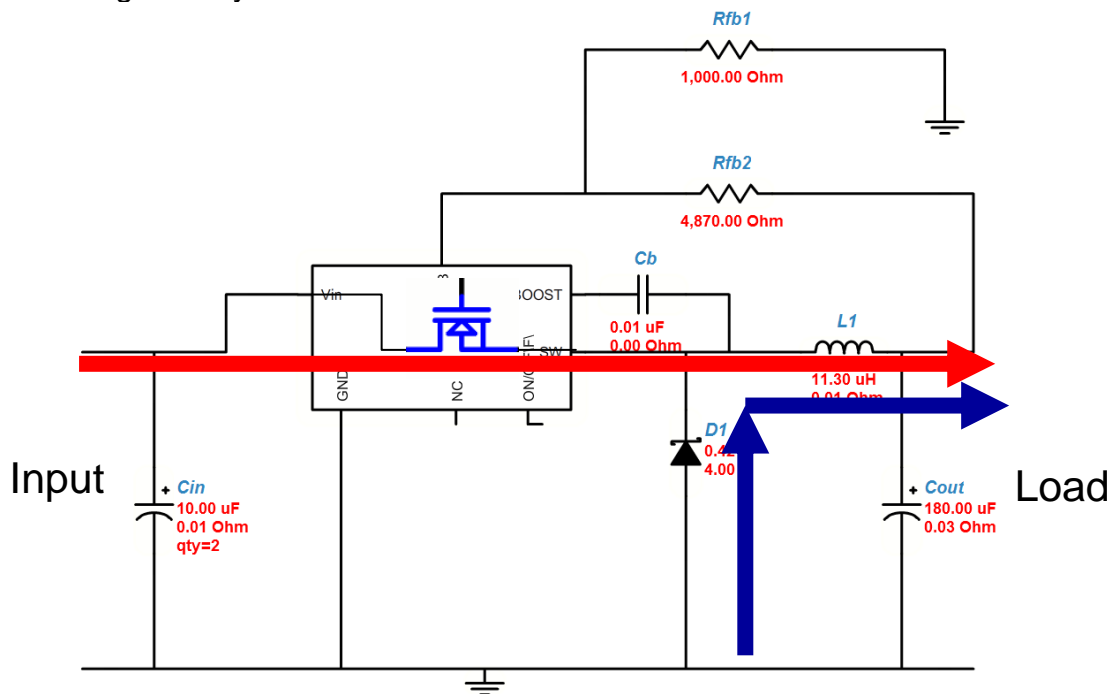
Power Supply Design Specifications

Before using a design tool, it is important for the designer to determine in advance basic specifications such as input voltage range, output voltage, load current and ambient temperature. Other inputs include performance factors such as Vout ripple and desired transient response. In addition, the user should have a good idea of the footprint and efficiency budgets. Design tools prompt the designer for these specifications as part of the initial process. Then the user is presented with a list of recommended components and topologies. The first decision to be made is choosing the topology. For example in the case of a step down application, a buck solution is normally the most cost effective due to the low component count, but a flyback topology may be required if isolation is needed or if the output voltage is very close to the input voltage. Another key parameter is the switching frequency of the regulator. If the user requires high efficiency, it is best to have a regulator that runs at low frequency (down to 100 kHz). On the other hand, a regulator with high switching frequency (up to 1MHz or more) is best if small footprint is desired. A regulator with user selectable frequency allows for more optimization possibilities. Other attributes to weigh include features such as soft start, variable current limit, and on/off capability.

The next step is the calculation of component values by the software. To achieve this, first the voltages and currents at each node in the circuit are calculated and safety margins are added to determine minimum component

limits. Targets for other component parameters are then determined by the desired performance. For example, the target for inductance is based on the ripple current goal which affects peak current and V_{out} ripple. Input capacitance is determined based on the desired input voltage deviation. Output capacitance is determined by the targeted output transient response. Components are thus automatically selected based on the component selection algorithms in the software.

Modeling and reducing power loss is essential to achieve high efficiency in a design. For an asynchronous integrated FET buck converter circuit, as shown in figure 2, the primary sources of loss occur in the main current path and consist of the regulator with internal FET, the catch diode, and the output inductor. Of these components, power dissipation is dominated by the FET and/or diode depending on the duty cycle, with high duty cycle designs having more loss in the FET and low duty cycle designs being dominated by losses in the diode. Power dissipation in the FET consists of DC losses determined by the R_{dsOn} characteristic of the FET and AC losses which are a function of the capacitance of the FET which affects the rise and fall time of the switch. Power loss in the diode is determined by the forward voltage drop and by the capacitance of the diode. Losses in the inductor are a function of the DC resistance and core material/geometry.



Current Path with Switch On

Current Path with Switch Off

Figure 2: Current Path through a Typical Buck Switching Regulator

AC Losses vs. Frequency

AC losses in the switch follow the following equation:

$$P_{swAC} = \frac{1}{2} * V_{ds} * I_{ds} * (t_{rise} + t_{fall})/t_{sw}$$

As shown in figure 3, AC switching losses occur when the switch is turning on and off and both current and voltage in the switch are non zero. These losses are relatively fixed in duration. But we have control over the switching time period (t_{sw}) for regulators which have user selectable frequency. Using low switching frequency/long switching period causes the rise/fall time to be a smaller percentage of each switching cycle and efficiency is raised. However, this increases the on time of the switch (dt) which requires increased inductance to keep the ripple current (dl) constant as per the basic inductance equation:

$$L = V * dt/dl$$

This results in more turns on the inductor and therefore a larger footprint.

Conversely, increasing the switching frequency reduces the footprint. Higher frequency reduces the switch on time (dt) and thus lowers the inductance required to get the same ripple current (dl). This will reduce the number of turns required and make for an inductor with smaller footprint. Unfortunately, high frequency designs lead to higher AC losses in the switch and worse power dissipation, the opposite of what was described above.

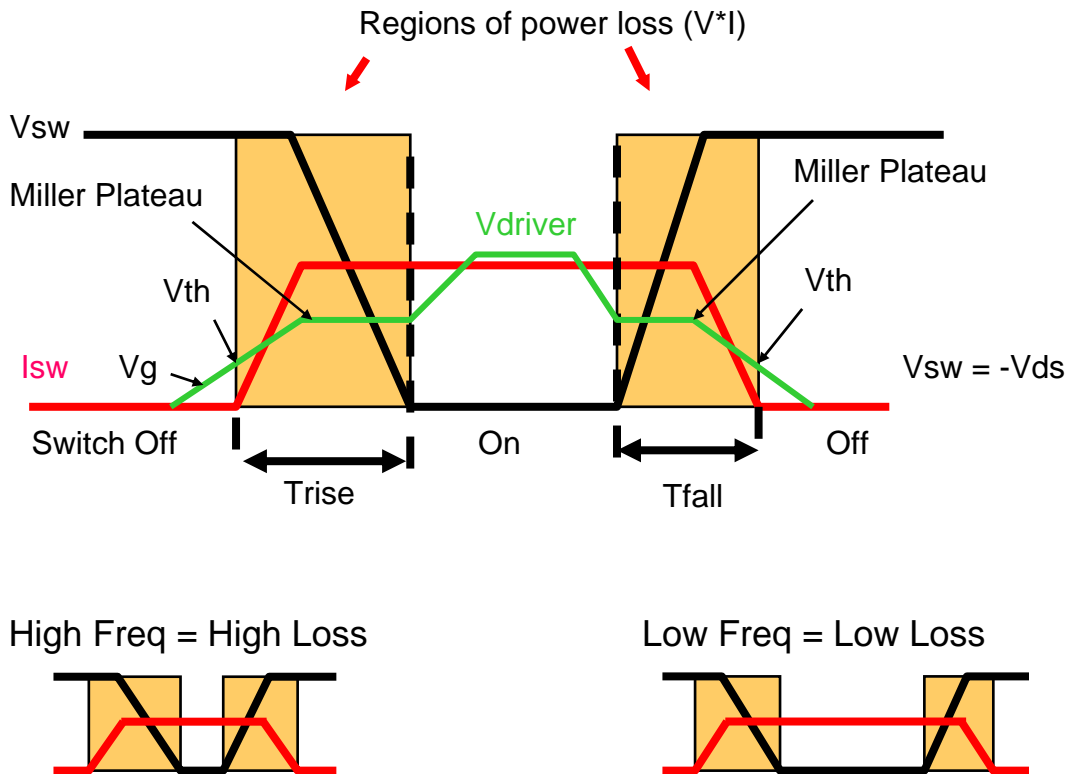


Figure 3: Symbolic View of AC Switching Power Losses

Optimizing for Efficiency vs. Footprint

A tool such as the WEBENCH Design Environment provides an easy method to optimize a buck controller design for efficiency or footprint or a balance between the two. A software knob control, as shown in figure 4, allows the user to select the desired outcome of optimization. If the user picks a high optimization setting to emphasize high efficiency, the frequency is lowered, which causes lower AC switching losses but higher footprint as described above. Conversely, if the user picks a low optimization setting to get a small footprint for the design, the frequency is raised which results in a smaller inductor and lower overall footprint, but worse efficiency. There are additional factors which are considered in the optimization process including parasitic resistance (ESR, DCR), component cost and availability. As can be seen the graph, intermediate results may offer good compromises between efficiency and footprint, such as the optimization 4 setting shown in figure 4 with an efficiency of 91% and a footprint of 350 square millimeters vs. the design in option 5 with 93% efficiency but a footprint over 1000 square millimeters.

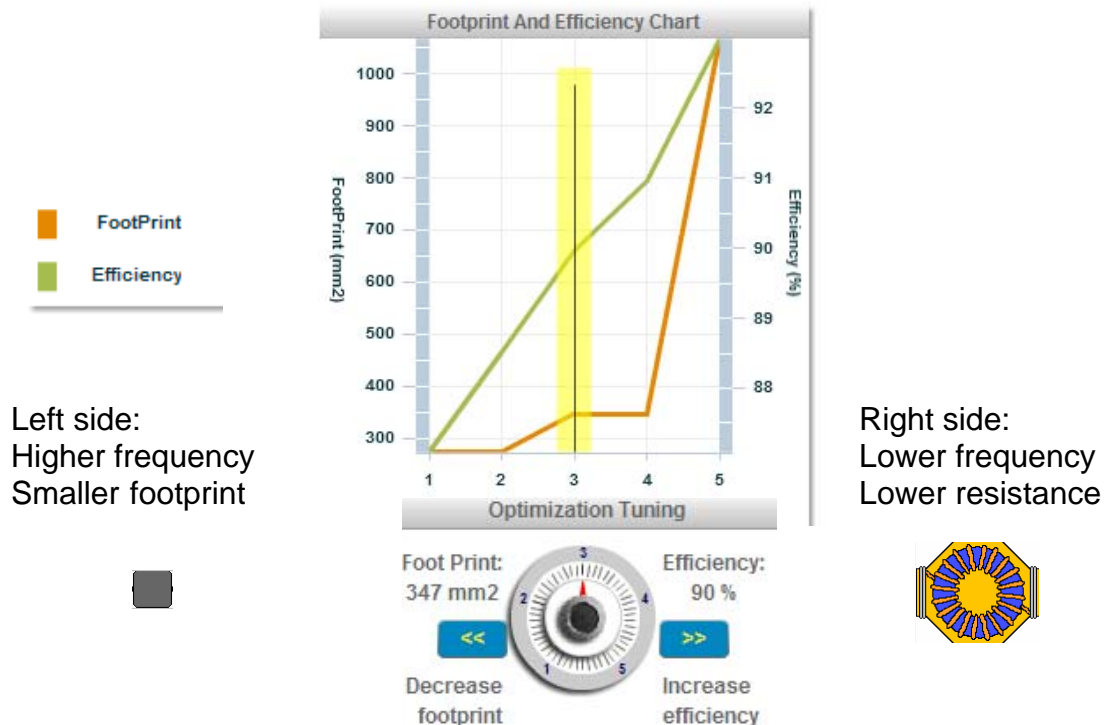


Figure 4: Optimization Of A Power Supply Design Showing Tradeoff between Efficiency and Footprint

Once a power supply has been optimized for performance, price must be taken into account. There are likely a number of possible components with similar parameters which meet the specifications for the design. If the designer is willing to compromise slightly on the efficiency, a lower priced component may be used with almost the same results. Figure 5 shows a graph of the design efficiency calculated for each pair of FET solutions in a synchronous buck design vs. the

relative price of the FET pair. A user can save 10% on the FET cost by taking a drop of about .4% in efficiency.

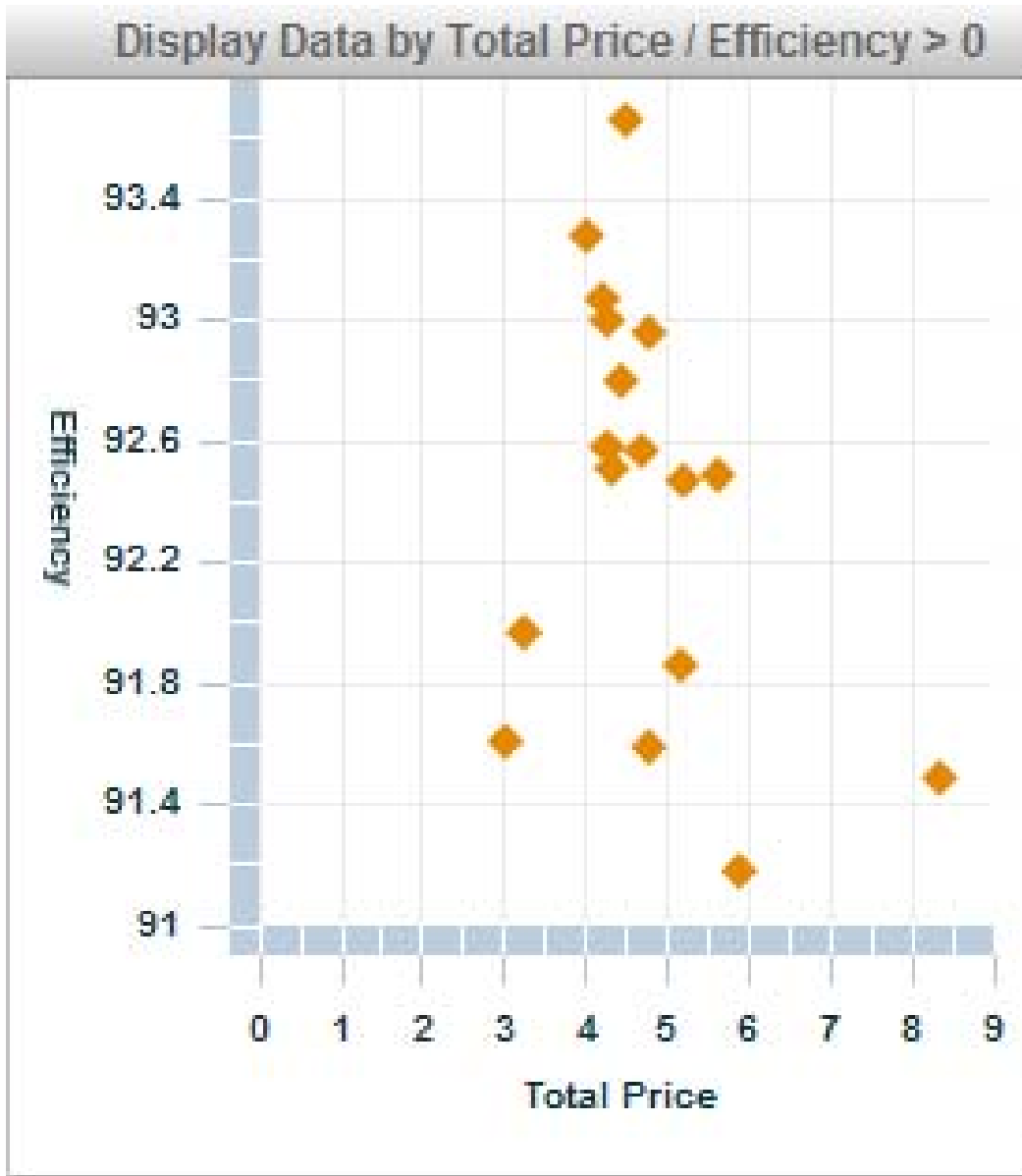


Figure 5: Pairs of FET Solutions for a Synchronous Controller Comparing Efficiency with Price

Electrical Simulation

Why do electrical simulation if the design has already been configured for stable operation? The user may want to observe dynamic circuit behavior, such as transient response, which is not readily discernable from static operating values. In turn, the designer may want to further tune the design for output ripple voltage, loop stability and/or transient response. A good design environment allows a user to run a number of different time domain simulations including start-up, input line transient, output load transient and steady state. A Bode plot, useful for

confirming system stability, is also essential. A waveform viewer which allows easy zooming and manipulation of waveforms is needed to analyze simulation results.

As an example, the load transient simulation allows easy comparison of two different regulators, one using a pulse width modulated (PWM) voltage control mode and the other using a hysteretic control mode. As can be seen in figure 6, the simulation shows that the hysteretic regulator circuit has much faster transient recovery time but more output ripple thus allowing the user to quickly select a regulator based on which attribute is most important.

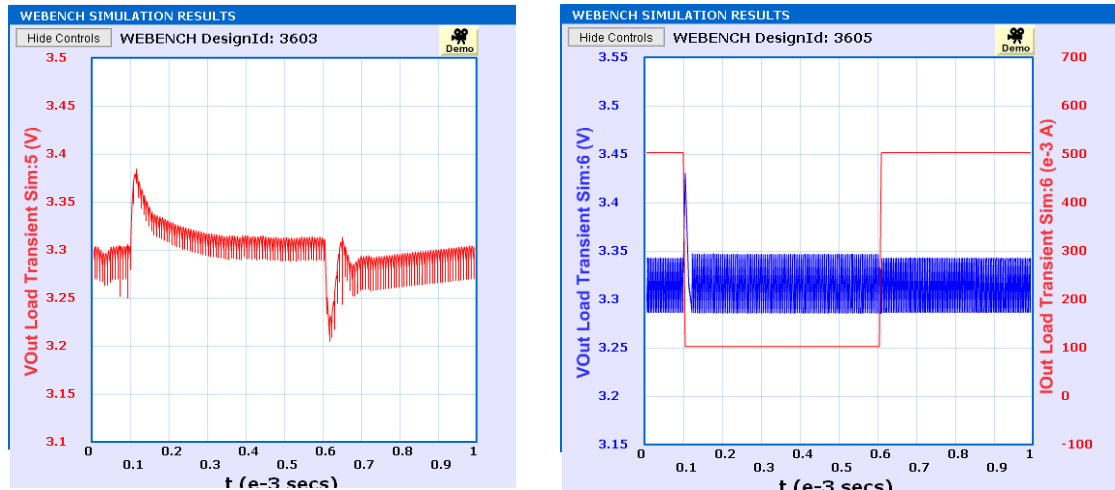


Figure 6: Load Transient Simulations for Voltage Mode PWM (left) vs. Hysteretic (right) Voltage Regulator Circuits using a Current Pulse going from .5 to .1A.

Solving Thermal Issues

Thermal simulation is an excellent tool for identifying and solving temperature problems in power supply circuits. Board level simulation takes into account co heating of adjacent components which traditional θ_{JA} calculations do not address. Thus if two components which dissipate significant amounts of power in a regulator circuit are located close together, the net effect can be higher than expected temperatures for each of them. To get good accuracy balanced with fast simulation, the type of model used for each component should be appropriate. For components dissipating small amounts of power, a lumped cuboid model based on the volume of the component is adequate and speeds simulation time. For components dissipating more power, a sophisticated model taking into account the component geometry and materials must be used. The copper traces on the board itself also affect the temperature and therefore should be modeled.

When a thermal problem is encountered, there are many ways to solve it. This might include moving components apart, increasing the copper thickness on the board, and increasing the amount of copper attached to components. More costly solutions include adding a fan and/or including an extruded heat sink. The

thermal simulation tool should allow the user to try out these options and quickly see the results. In figure 7, a 5A power supply using an integrated switch voltage regulator initially starts out hot. By running thermal simulations, it is found that using a fan or an attached heat sink with larger board layout brings the temperature down to acceptable levels.

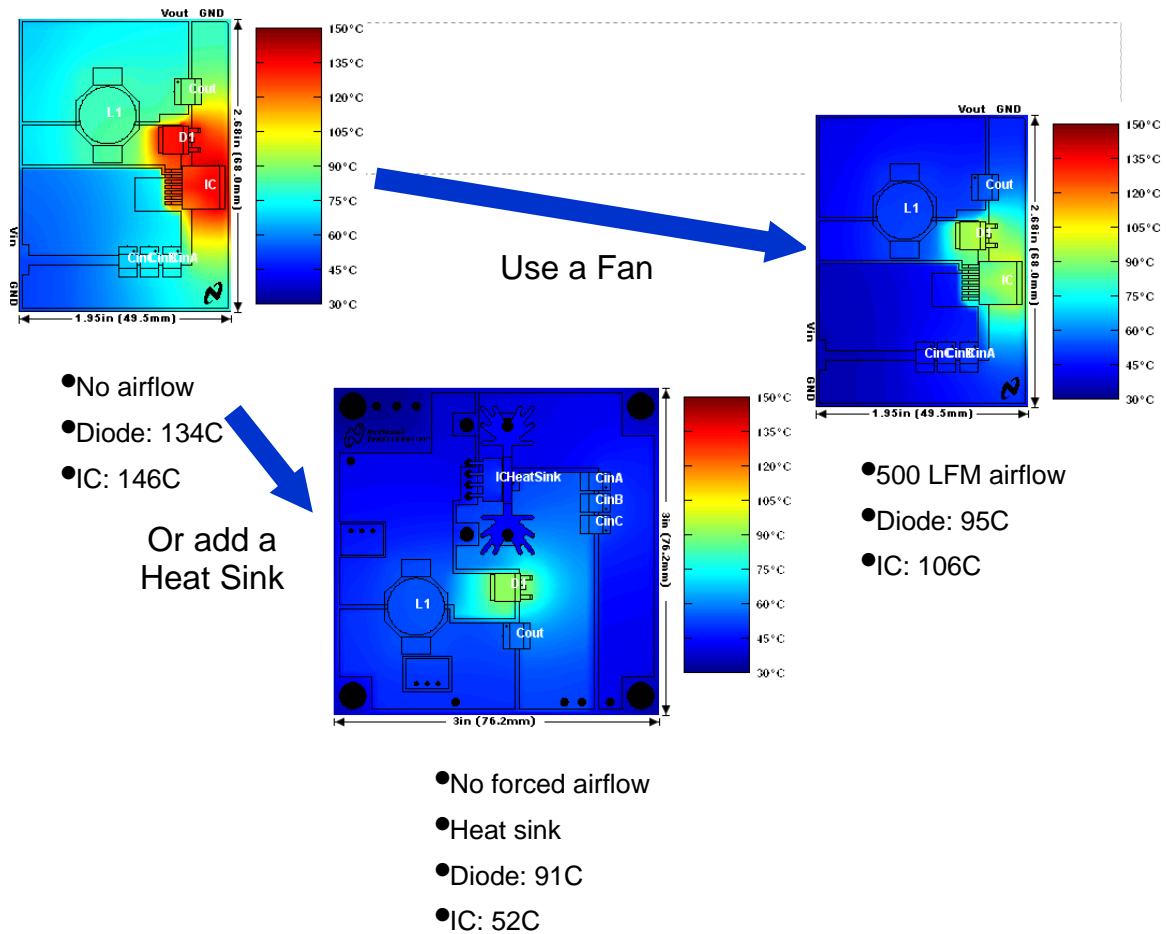


Figure 7: Thermal Simulation Results for a 5A Integrated Switch Power Supply

Building a Prototype and Documenting the Design

After using design tools to optimize a power supply design, it is still important to build a prototype. This is because simulation, even after extensive verification of models, may not be completely accurate or take into account all factors under all conditions. The ability to quickly obtain samples, evaluation boards and complete custom kits with on line ordering and overnight shipment capability is a key attribute. In this way, a prototype can be quickly constructed and evaluated to make sure the result is what was desired. Downloadable schematic, layout and Gerber files ease the integration of the power supply into the designer's overall circuit.

Lastly, automatic documentation of the design with the schematic, bill of materials, graphs of operating values and simulation results provides a record for

future reference and reuse. This greatly eases a task which can tend to be skipped under the normal pressures of getting a product released.

In summary, design tools such as National Semiconductor's WEBENCH Design Environment, available at <http://www.national.com>, allow optimization of power supplies through visualization of tradeoffs such as efficiency, footprint and price using real world components. The result is a power supply which is better tailored to the requirements of a customer's proprietary circuit than simply using a fixed reference design from a datasheet. In addition, end to end design and prototyping is achievable in a very rapid manner which reduces the design cycle time and brings designs to market faster.