AP-6

Thermal Management of UltraVolt HVPSs

Any electronic device's long-term reliability is directly related to how the overall system design allows it to dissipate any generated heat properly. Likewise, the long life and reliability of UltraVolt high-voltage power supplies (HVPSs) will be enhanced through proper thermal management.

Due to the laws of physics, the process of converting one voltage level to another cannot be done without energy loss; that loss, the power used to operate the power supply itself, is usually dissipated as heat. UltraVolt HVPSs have excellent efficiency ratings, ranging from 75% to 92% at full output power (depending upon the model), delivering full rated voltage at nominal operating conditions. The remaining fraction of the HVPS's input power is converted to heat. Methods of properly dissipating this heat can be found in this application note.

The operating efficiency of a power supply — one of the key variables in thermal calculations — can be determined in different ways. The Acceptance Test Procedure (ATP) that came with your UltraVolt power supply contains a few common operating points and related data. The ATP data can be used to determine the supply's operating efficiency at various points. Alternately, the efficiency of a particular UltraVolt HVPS under specific operating conditions can be obtained from our Customer Service Department. Typical operating efficiency is also listed in the DC Efficiency vs. Input Voltage Range graph of the power supply's data sheet. This graph shows only typical values for the various models in that series of power supplies.

The analysis and several sample calculations in this application note are divided between *Units without user-supplied heat sinks (and -H option units)*, and *Units with user-supplied heat sinks (and other cooling methods)*.

Units without user-supplied heat sinks (and -H option units):

An UltraVolt 2A12-P4 is continuously delivering its nominal 2mA at 2kV (P_{DCout} = 4W) with a nominal 12VDC input. The input current is reported as 390mA (P_{DCin} = 4.68W), based on the ATP at this operating point (nominal output power, nominal 12V input voltage).

We can determine the heat energy dissipated as

$$P_{heat} = P_{DCin} - P_{DCout}$$

where

$$P_{DCin} = V_{in} I_{in}$$

and the unit's efficiency is

$$P_{DCout} / P_{DCin}.$$

Solving for P_{DCin} yields

$$\begin{aligned} P_{DCin} &= V_{in} I_{in} = ((12V)(0.39A)) \\ &= 4.68W. \end{aligned}$$

$$\text{So, } P_{heat} = P_{DCin} - P_{DCout} = (4.68W) - (4W)$$
$$= 0.68W.$$

Thus, efficiency $= P_{DCout} / P_{DCin} = (4W) / (4.68W)$
$= 86\%$.

Therefore, this power supply will dissipate 0.68W of heat when operated as per the discussed operating conditions. At this operating point, its DC efficiency is 86%.

For an "A" Series UV HVPS (for example, the 2A24-P4) with the standard plastic case, no extra heat sinking, and all surfaces exposed to free air, calculate the temperature rise of the power supply's case under these conditions. Assume the HVPS is mounted in sockets on the printed circuit board (PCB).

First, the total surface area (*SA*) of the standard 4W "A" Series must be calculated. The *SA* can be calculated from simple geometry, since the HVPS has 6 sides consisting of 3 sets of 2 equal sides. (Dimensions can be found in the "A" Series datasheet, where *l* represents Length, *w* is Width, and *h* is Height.) Solving for surface area we find,

$$SA = 2\,(lw + lh + wh) = 2\,((3.7\text{in})(1.5\text{in}) + (3.7\text{in})(0.77\text{in}) + (1.5\text{in})(0.77\text{in}))$$
$$= 19.11\text{in}^2.$$

It is universally accepted that 1W will raise 1in^2 approximately 100°C for all surface area exposed to free, still air (assumptions made for simplicity). Since we are dissipating 0.68W,

$$\Delta T = (P_{heat} / SA)(100°\text{C} \cdot \text{in}^2 / \text{W}) = (0.68\text{W} / 19.11\text{in}^2)(100°\text{C} \cdot \text{in}^2 / \text{W})$$
$$= 3.56°\text{C}.$$

Finally, assuming the enclosure within which the UV HVPS is placed has a continuous operating temperature of 40°C ($T_{ambient}$), we have a final UV HVPS case temperature of 43.56 °C ($\Delta T + T_{ambient}$). Thankfully, this value is comfortably below the recommended maximum "A" Series operating temperature of 65°C. In practice, the actual case temperature may be slightly different than the expected value, depending upon the mounting of the power supply and the heat dissipation properties of that mounting.

The power supply will also have certain areas that are warmer and other areas that are cooler because certain components within the unit dissipate more heat than others. These warm areas are generally referred to as "hot spots." Note, flush-mounting this power supply onto a PCB will hinder any convection cooling along the surface of the power supply that faces the circuit board. To account for this, the *SA* calculation of this particular example is carried out by summing the 5 exposed sides, ignoring the cooling effect of the mounting surface. Alternately, if the power supply is PCB-mounted using sockets, then the mounting side will allow slight cooling by convection; this should be accounted for in the calculations using a scaling factor. A discussion of mounting methods for UltraVolt high-voltage power supplies appears in Application Note #3.

As seen in the calculations above, a 4W unit running at full rated power rarely needs any supplemental heat sinking. However, a 20W, plastic-encased "A" Series running continuously at full power will dissipate approximately 3.5W, assuming 85% efficiency (which is a rough approximation used only for this example; do not use this number for your own calculations). Without any supplemental heat sinking and with one surface of the power supply mounted onto a PCB, the case temperature will rise 26°C, an unacceptable temperature increase in applications with more than a 40°C ambient temperature. The design of 20W "A" Series, as well as all other UV modular HVPSs, facilitates easy interfacing to a heat-dissipation medium. The top surface of the 20W, plastic-case "A" Series is actually a 0.062"-thick aluminum plate, which will efficiently conduct heat to an external heat-sink medium, such as a chassis wall or other customer-supplied heat sink. This aluminum plate also helps regulate internal power supply hot spots, which occur because of the heat dissipations of different components within the power supply itself (as mentioned previously).

A 4A24-P20-H (a 4kV, 20W supply) delivering 2500V at 3mA (much less than the rated 20W out), draws .46A from its 24V supply. Solving for P_{heat},

$$\begin{aligned} P_{heat} &= P_{DCin} - P_{DCout} = ((24V)(0.46A) - (2.5kV)(3mA)) \\ &= 3.54W. \end{aligned}$$

Therefore, this power supply will dissipate 3.54 watts of heat when operated, according to the operating conditions (68% efficiency due to the light load). For comparison purposes, a 4A24-P20-H running at full output voltage has been analyzed in the appendix of this Application Note, providing a typical 89% efficiency example.

For the previously mentioned power supply, flush-mounted to a PCB, with the -H (heat sink) option, and with all sides except the mounting side exposed to free air, calculate the temperature rise of the power supply's case.

First, the **exposed** surface area of the standard 20W “A” Series must be calculated. From simple geometry (dimensions from “A” Series datasheet), the *SA* of the sides exposed to free air (neglecting the mounting and the heat sink sides) can be calculated as

$$\begin{aligned} SA_1 &= 2(lh + wh) = 2((3.7in)(0.77in) + (1.5in)(0.77in)) \\ &= 8.01in^2. \end{aligned}$$

The -H heat sink adds approximately another $13in^2$ of surface area, so the total exposed still-air surface area is

$$\begin{aligned} SA_{tot} &= SA_1 + SA_{hs} = (8.01in^2) + (13in^2) \\ &= 21.01in^2. \end{aligned}$$

It is again assumed that 1W will raise $1in^2$ of surface area approximately 100°C (in still air, which we will assume here for simplicity).

Since we are dissipating 3.54W, we can calculate ΔT as

$$\begin{aligned} \Delta T &= (P_{heat} / SA_{tot})(100°C \cdot in^2 / W) = (3.54W / 21.01\ in^2)(100°C \cdot in^2 / W) \\ &= 16.85°C. \end{aligned}$$

If the enclosure within which the UV HVPS is placed has a continuous operating temperature of 40°C, we will have a final UV HVPS average case temperature of 56.9°C. (Again, due to the differing heat dissipations of certain components within the power supply, certain regions of the unit will be warmer than others.) Of course, this value is below the recommended maximum “A” Series operating temperature of 65°C.

It is important to consider that all of our calculations have assumed the power supply is supplying a continuous amount of power. Low duty-cycle or pulsed operation of a UV power supply may dissipate a considerably smaller amount of average heat than the calculations here have yielded. In these situations, the HVPS may not need supplemental heat sinking. For example, a power supply operating at a 10% duty cycle will dissipate a small fraction of the continuous full-output dissipated heat (and hence can be operated without supplemental heat sinking).

Note, should these units be operated at less than full-rated output power, their operating efficiency will be less than their potential maximum efficiency. UltraVolt power supplies are designed to operate most efficiently when delivering their full-rated output power.

In summary, when dealing with an HVPS unit that does not have any supplemental heat sinking (or has only a -H heat sink), a few basic rules can be followed to simplify calculations. When calculating the surface area of the unit, ensure only sides that have access to free, open air are included in the calculations. If a side is in close proximity to a surface, such as a high-voltage power supply mounted with sockets onto a PCB, a fraction of the actual surface area of the hindered side(s) should be included in the calculations. If a -H heat sink is used, be sure that its side is summed into the equation for surface area only once (for that particular side, the 13in^2 surface area of the -H heat sink is the surface exposed to air).

Units with user-supplied heat sinks (and other cooling methods)

Through testing, an UltraVolt 6C24-P125 is determined to draw 5.9A from its 24V supply while delivering 6kV into its rated load.

Under the above operating conditions, determine whether a fully enclosed metal container of dimensions 12” x 6” x 4” (288in^2 total surface area) will sufficiently cool this HVPS if it is mounted to the wall inside the chassis. (Only the exterior of the container is exposed to the outside free air.) All sides of the metal container are exposed to free air. Assume the container is a good thermal conductor and has a low thermal-resistance interface between the HVPS and the container.

Therefore,

$$P_{heat} = P_{DCin} - P_{DCout} = ((24V)(5.9A)) - 125W$$
$$= 16.6W \text{ (88\% efficiency).}$$

Here, since the HVPS is mounted inside the enclosed container, the surface of the HVPS will not directly dissipate its heat to the outside air. Instead, it will transfer its thermal energy to the chassis. The only surface that can dissipate heat to the outside air is the chassis' surface. The cooling provided by the HVPS's surface inside this container is negligible compared to the cooling provided by the heat transfer from the HVPS to the chassis wall. We approximate the dissipating surface area to be 12” x 12” x 2” = 288in^2.

Since we are dissipating 16.6W,

$$\Delta T = (P_{heat} / SA_{tot})(100°C \cdot in^2 / W) = (16.6W / 288in^2)(100°C \cdot in^2 / W)$$
$$= 5.7°C.$$

A chassis temperature increase of 5.7°C should be quite acceptable under nearly all circumstances. So in conclusion, the HVPS would operate quite satisfactorily from a thermal standpoint.

In the above example, we made some assumptions that will now be discussed. First, it was assumed that a low thermal-resistance interface was used between the HVPS and the chassis wall. This implies the HVPS can transfer its heat to the heat sink - the chassis in the above example - without hindrance. In practice, this can be accomplished using an excellent heat-conduction medium, such as thermal elastomer (0.010” or 0.020” are common thicknesses), double-sided thermal tape, or thermal grease. This heat-conduction medium is then placed between the HVPS and the heat sink, and the HVPS is securely mounted to the heat sink using the proper bracket and/or mounting fasteners. These fasteners are then torqued sufficiently to guarantee the correct contact pressure on the heat-conduction medium. For example, the #8 studs on a 60W unit should be torqued to 8ft • lb of torque to ensure the proper ‘cold flow’ of a thermal-elastomer heat-conduction medium. Remember, in order to keep the thermal resistance low between the HVPS and its heat sink (allowing the greatest transfer of heat), the HVPS should have as much surface area as possible facing the smooth heat-sink medium (via the heat-conduction medium).

Second, it was assumed the heat-sink medium — the chassis wall in the above example — was a good conductor of heat. This assumption simplifies calculations by allowing us to utilize the entire open-air, exposed surface area of the heat sink as a dissipation medium (since the heat to be dissipated is easily conducted to the exposed surface area of the dissipation medium). Not surprisingly, heat sinks are usually made from metals known for their excellent heat conduction properties (such as aluminum).

When cooling an HVPS, many design variables enter into the equation and can determine how actual implementation is carried out. Airflow is one very important variable, and is, unfortunately, too complex to fully analyze here. Generally speaking, forced-air cooling from a simple fan can drastically reduce the size of a required heat sink, since the flowing air removes the dissipated heat more efficiently (by transferring the heat to a larger volume of air and not relying solely on convection). The ambient temperature of the HVPS's surroundings is also a very important variable. A 15°C temperature increase may be acceptable if the ambient is 25°C, but may be totally unacceptable if the ambient temperature is 60°C (due to other devices within the same chassis dissipating a large amount of heat, for example). The mounting method is another crucial design variable.

If the HVPS is mounted to a large chassis wall, then it is unlikely a supplemental heat sink will be required.

Oddly enough, one of the most important considerations when it comes to cooling design is to allow for a large margin of safety. Even common dust coating a heat sink can drastically reduce its cooling effectiveness. Obstructed or dust-coated fan vents can seriously reduce the cooling efficiency of the fans themselves. The importance of air-vent filters and regular cleaning becomes obvious. Also, load changes (due to slight design changes) can require more power to be delivered from the HVPS and, hence, change its actual heat dissipation. In summary, include a large margin of safety in your heat calculations to ensure your high-voltage power supply cools sufficiently under all conditions. This can be achieved simply by assuming the power supply will operate in an ambient temperature higher than previously calculated.

Although one can carry out thermal calculations using thermal junction analysis and actual thermal resistance values, we have not opted for that method here. While they will yield more accurate results, the methods described here will sufficiently approximate the cooling requirements for your HVPS, given an adequate safety margin. Complex cooling requirements, such as very limited space restrictions with forced-air cooling may require a more in-depth analysis than proposed here. In these cases, we recommend you consult both a text on thermal management and UltraVolt's Customer Service Department. Remember to keep your UltraVolt HVPS cool, and it will reward you with a long, trouble-free life.

Surface Area of UltraVolt Models

UltraVolt Model	Total Surface Area (in square inches)
“A” / with -F / with -C / with -F-C	19.11 / 25.26 / 28 / 37.69
“10A” / with -C	20.46 / 29.2
“15A” / with -C	25.26 / 35.4
“20A” / with -C	31.5 / 43.2
“25A or 30A” / with -C	39.93 / 57
“C” / with -C	19.11 / 28
60W/125W “C”	54.28
250W “C”	98.88
“8C - 15C”	98.88
“20C - 25C”	98.88

Appendix:

A 4A24-P20-H (a 4kV, 20W supply) delivers 4kV at 5mA (the rated 20W out), and draws .94A from its 24V supply, operating at 89% efficiency. The heat energy dissipated is

$$P_{heat} = \mathrm{P_{DCin}} - \mathrm{P_{DCout}} = ((24\mathrm{V})(0.94\mathrm{A})) - ((4\mathrm{kV})(5\mathrm{mA}))$$
$$= 2.56\mathrm{W}.$$

This power supply will dissipate 2.56W of heat when operated as described above.

For the previously mentioned power supply, flush-mounted to a PCB, with the -H (heat sink) option, and with all sides except the mounting side exposed to free air, calculate the temperature rise of the power supply's case.

First, the **exposed** surface area of the standard 20W “A” Series must be calculated. From simple geometry (dimensions from the “A” Series data sheet), the *SA* of the sides exposed to free air (neglecting the mounting and the heat sink sides) can be calculated as

$$SA_1 = 2(lh + wh) = 2((3.7\mathrm{in})(0.77\mathrm{in}) + (1.5\mathrm{in})(0.77\mathrm{in}))$$
$$= 8.01\mathrm{in}^2.$$

The -H heat sink adds approximately another 13in^2 of surface area, so the total exposed still-air surface area is

$$SA_{tot} = SA_1 + SA_{hs} = (8.01\mathrm{in}^2) + (13\mathrm{in}^2)$$
$$= 21.01\mathrm{in}^2.$$

It is again assumed that 1W will raise 1in^2 of surface area approximately 100°C (in still air, which we will assume here for simplicity).

Since we are dissipating 2.56W, we can calculate ΔT as

$$\Delta T = (P_{heat} / SA_{tot})(100°\mathrm{C} \cdot \mathrm{in}^2 / \mathrm{W}) = (2.56\mathrm{W} / 21.01\mathrm{in}^2)(100°\mathrm{C} \cdot \mathrm{in}^2 / \mathrm{W})$$
$$= 12.2°\mathrm{C}.$$

Assuming the enclosure within which the UV HVPS is placed has a continuous operating temperature of 40°C, we have a final UV HVPS average case temperature of 52.2°C. This value is comfortably below the recommended maximum “A” Series operating temperature of 65°C.