

Introduction

When designing a new application, one parameter that should be considered early in the design cycle is the thermal management of the end device. Designing with thermal management at the forefront of your process will ensure the optimal and most cost-effective solution required to keep temperatures within design parameters.

Every application has different requirements, so it is not possible to provide a single most cost-effective thermal management solution for every situation. This document explores the thermal management options available when designing using Silvertel's different Power Modules, one or more of these options may be incorporated into a design to achieve the optimal thermal management solution.

When comparing two functionally equivalent modules with no consideration for thermal management, if one module is smaller, meaning it has a higher power density, the smaller module may get hotter, but this is not necessarily due to the smaller module dissipating more power than the larger equivalent, however this is in fact due to the lower thermal mass causing a faster temperature rise within the smaller surface area. This results in a lower transfer of heat into the passing airflow causing higher settling temperatures. It is essential that the thermal performance of a design is considered regardless of size or power consumption of the application.

Silvertel produces Power over Ethernet (PoE) and DC-DC converter modules in three form factors, Single in Line (SIL) through hole, Dual in Line (DIL) through hole, and Surface Mount (SMT). Each of these formats has its own range of benefits for any given project. The core of Silvertel PoE modules is a compact DCDC converter.

Single in Line (SIL) Modules

SIL modules feature a single through hole connector pin footprint and offer the benefit that, as the circuitry of the module is positioned perpendicular to the host PCB, it takes a relatively small amount of host PCB area. Protruding from the host PCB allows for the components on both sides of the module to be in the path of air flow, which makes this format ideal for applications where there are air currents passing through the application enclosure. The thermal management of a SIL module becomes more challenging when the application has limited airflow. Examples of our SIL modules include the Ag9700 series, the Ag5400 series, and the Ag7200 series.

Dual in Line (DIL) Modules

DIL modules feature two rows of through hole connector pins mounted on the bottom side of the module. The module is mounted parallel to the host PCB, which allows for a thermal interface material (TIM) to be used between the module and the host PCB, drawing the thermal energy out of the module and sinking it into copper planes in the host PCB. The DIL footprint allows for the higher power dissipating components to be located on the underside of the module, allowing the thermal energy to be directly pulled out of the component casing and surrounding PCB area, and reducing its heating effect on the surrounding components on the module. Examples of our DIL modules include the Ag5800, Ag5810 and Ag7100.

Surface Mount (SMT) Modules

SMT modules feature a right angle pin headers or block connectors on the modules underside and are mounted parallel to the host PCB, this allows for a thermal interface material (TIM) to be used between the module and the host PCB, drawing the thermal energy out of the module and sinking it into copper planes in the host PCB. This allows for the higher power dissipating components to be located on the underside of the module, allowing the thermal energy to be directly pulled out of the component casing and surrounding PCB area, and reducing its heating effect on the surrounding components on the module. Examples of our surface mount modules include the Ag9900-MTB and Ag9900-LPB series, The Ag5700-LPB series, and the latest releases, our Ag7300, Ag6130 and Ag59600-LPB series.

Ambient Temperature

The operating temperature range specified in Silvertel's datasheets relates to the temperature of the air surrounding the module and not the temperature outside any enclosure, See Figure 1. If an application has movement of air flowing over the module, the temperature of this air will be the ambient air temperature. In applications where there is no or very limited movement of air around the module, the ambient temperature should be taken in close proximity to the module, ideally surrounding the highest power generating component.

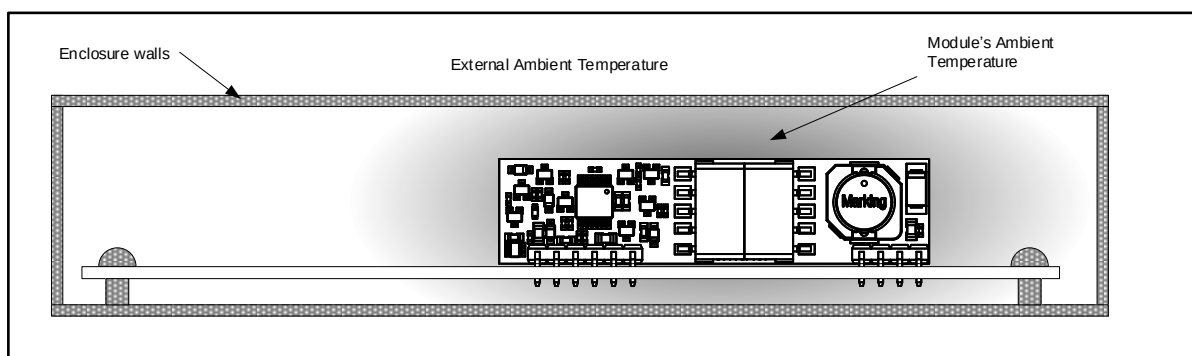


Figure 1: Ambient temperature

Conduction

With air having a typical thermal conductivity of just $0.03 \text{ Wm}^{-1}\text{K}^{-1}$ compared to copper which has a thermal conductivity of roughly $400 \text{ Wm}^{-1}\text{K}^{-1}$, the most effective method of reducing heat from the module is by making use of thermally conductive materials to sink the thermal energy and distribute over a larger surface area, where it can be more readily dispersed into the air passing by the application.

Thermal Interface Materials (TIMs)

There are a range of different TIMs that can be used for thermal management, any product used in contact with Silvertel's modules should not be electrically conductive. It is recommended that any material used have a lower electrical conductivity than air to ensure adherence with maintaining the 1500V isolation requirements of the IEEE802.3 specification.

Thermal Gap Pads

Thermal Gap Pads are sheets of a compressible silicone-based material often reinforced with fibreglass. Gap pads are designed to be compressed by up to 50%, conforming to and encapsulating the components. With typical thermal conductivities ranging from $1 \text{ Wm}^{-1}\text{K}^{-1}$ to $4 \text{ Wm}^{-1}\text{K}^{-1}$, gap pads are a very effective method of bridging two thermally conductive materials such as between one of Silvertel's DIL modules and the host PCB, or the host PCB and the enclosure wall.

These materials can be purchased as sheets and cut to size or precut to custom sizes and shapes for a given application but are not suitable for use with SMT modules, due to the pressure required for them to conform to the underside of the module, which is not practical in common reflow processes.

Thermal Gap Fillers

Thermal gap fillers are silicone-based gels with thermal conductivities typically ranging from $2 \text{ Wm}^{-1}\text{K}^{-1}$ to $7 \text{ Wm}^{-1}\text{K}^{-1}$. Gap fillers will conform to and retain the shape of the components on the underside of the module making these products suitable for Silvertel's SMT and DIL products.

These materials are available in 1 or 2 part solutions that can be dispensed by an automated dispenser during assembly, or manually prior to or after assembly. However, being a silicone-based material, the maximum operating temperature of these materials will be 200°C . At temperatures above 200°C , silicones mechanical properties will begin to change, however in a typical reflow process the time spent above 200°C is not long enough to noticeably degrade the material, making Gap fillers suitable for a single electronics reflow.

Thermally Conductive Silicone Adhesive

Silicone RTV adhesives can be used under Silvertel's modules. They cure to a firm consistency that can provide some mechanical fixing strength to the module, but they typically have a lower thermal conductivity than gap fillers, typically less than $2 \text{ Wm}^{-1}\text{K}^{-1}$, and can make removal of the module more difficult.

Potting Compounds

Potting compounds are a suitable option for thermal management in some applications. This solution involves fully encapsulating a circuit board with a thermally conductive compound, displacing all air. Potting compounds are poured in a liquid state into an enclosure that houses the circuitry to be potted, the compound then cures into a solid, often rubberised with a variety of hardnesses available.

Despite having a worse thermal conductivity than the other TIMs listed, at around $0.2 \text{ Wm}^{-1}\text{K}^{-1}$ to $1 \text{ Wm}^{-1}\text{K}^{-1}$ the contact area from full encapsulation alongside the mechanical properties of potting compounds can make them a suitable method of thermal management, particularly when the application is required to operate in harsh environments.

Potting compounds make repair or failure analysis difficult or impossible, for this reason Silvertel does not recommend the use of potting compounds on its modules and cannot provide a warranty on any modules that have been encapsulated in a potting compound.

Graphite Foam Gaskets

Graphite foam gaskets consist of a sheet of PGS graphite wrapped around a compressible foam pad. PGS (Pyrolytic Graphite Sheet) is a very good thermal conductor but very thin, with thermal conductivities ranging from $500 \text{ Wm}^{-1}\text{K}^{-1}$ to $1900 \text{ Wm}^{-1}\text{K}^{-1}$ in thicknesses of 0.1mm to 0.02mm respectively. By Wrapping the thin sheet around foam allows the thermal energy to be bridged between two materials through the surface of the material.

Graphite foam gaskets are an expensive thermal management product meaning their usage will normally be limited to applications where other solutions are not viable. It should also be noted that graphite is conductive so consideration should be taken when deciding suitability.

Heat Planes

The simplest method of drawing thermal energy out of the module is to position copper pours on the power pins of the module at no additional cost. This will allow the thermal energy built up in the module to conduct through the module's terminations, and into the copper of the host PCB, where it can be spread across a larger area. It is for this reason that Silvertel advises against the use of sockets for through hole mount modules, as the smaller contact area of the socket will provide less thermal conduction and a higher contact resistance to the host PCB.

Copper pours on the outer layers of the PCB will allow the thermal energy to be dissipated into any airflow passing over the host PCB, while inner layers can be used as sinks to absorb and spread the thermal energy across the PCB where tracing on outer layers would prevent.

In applications where higher power is only drawn in bursts, using copper pours that can sink the thermal energy during the high-power burst, and then dissipate it slowly during the periods of low power usage, may be sufficient to keep temperatures within target limits.

Thermal Vias

Using a copper pour on a layer is a very effective method of spreading the thermal energy across a layer, however, transmitting the thermal energy through the PCB using the FR4 material to conduct between the layers is far less effective. FR4's thermal conductivity is typically around $0.2\text{--}0.3 \text{ Wm}^{-1}\text{K}^{-1}$. The best method of transmitting heat through the PCB is to place small copper plated vias at regular intervals where planes on different layers overlap, to lower the thermal resistance between the layers, helping distribute the thermal energy more effectively.

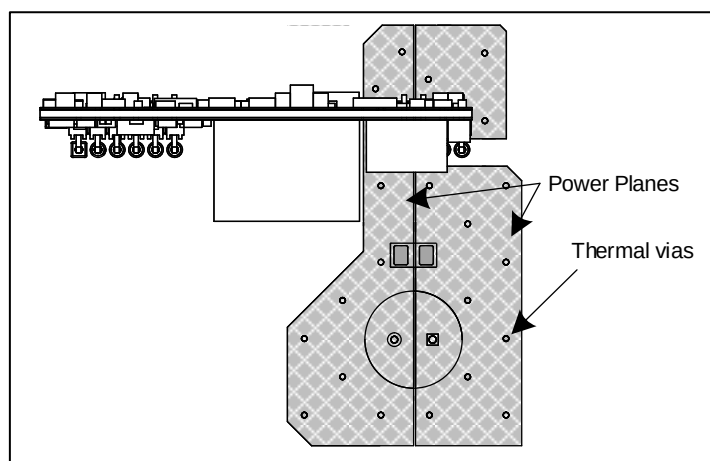


Figure 2: Example Heat Planes of a SIL Module

Thermal Via Arrays

With the SMT and DIL packages, typically the highest power dissipating components have been positioned on the underside of the module directly above the host PCB. Arrays of tightly spaced copper plated vias can be used, as shown in Figure 3, alongside a Thermal interface material (TIM) to directly draw heat out of the component and distribute it into copper pours on the different layers of the host PCB. The locations of these thermal via arrays will be detailed in the datasheet of any applicable Silvertel module.

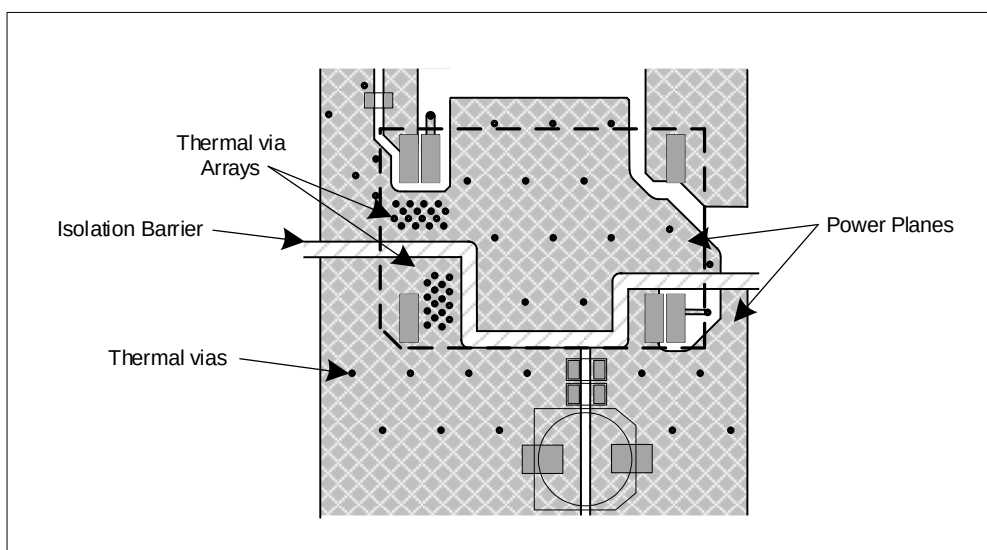


Figure 3: Example Heat Planes of an SMT Module

Enclosure Wall Heatsinking

The most effective method of managing the thermals in an application is to remove the thermal energy from the enclosure before it can raise the temperature of the air inside, this can be done by directly heatsinking the highest power dissipating components to the enclosure walls, allowing the thermal energy to be dissipated into the environment outside of the enclosure.

While this method of heatsinking is best suited to applications using metal enclosures, it can also be used with some effect to enclosures made of plastic. When using this method with a plastic enclosure the lower thermal conductivity of the plastic enclosure should be negated by spreading the heat over a larger area by using more thermal interface material (TIM).

The TIM most suited to creating a thermal bridge between the enclosure wall and PCB or components inside is thermal gap pads as these can be cut to size and added to the enclosure during final assembly.

SIL Modules

A further technique that can be used with a SIL module, is by positioning the module such that the rear side is inline or overhanging the edge of the host PCB, this allows a thermal gap pad to be sandwiched between the modules PCB and the enclosure wall, See Figure 4. A suitably compressible gap pad that will conform to the shape of the module without causing excessive strain on the module's mounting should be selected for this implementation.

Electrical Isolation is another consideration that should be taken into account with this solution being used with metal enclosures. As the rear of the module contains components that are either side of the 1500V isolation barrier required by the IEEE802.3 specification, placing the module too close to the enclosure wall would allow for the possibility of arcing across this barrier, whilst increasing the distance will reduce the performance of the thermal managing solution. One method to alleviate this concern is to oversize the gap pad so that it is slightly larger than the module, this will encapsulate any conductors that could form a point of arcing. An alternative is to apply a non-conductive sheet to the enclosure wall alongside a smaller thermal gap pad.

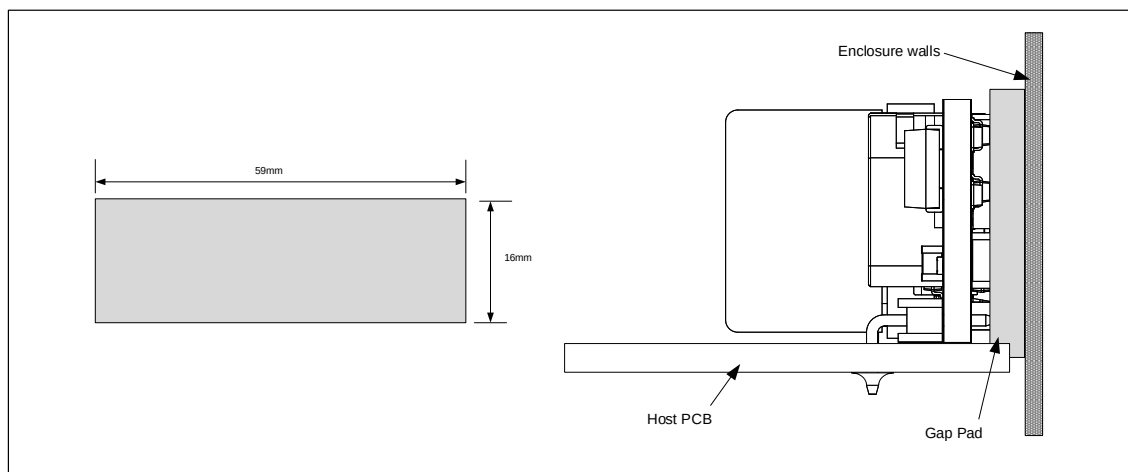


Figure 4: Example Enclosure Heatsinking with a SIL Module

SMT and DIL Modules

The simplest method of improving thermal performance with an SMT or DIL module with thermal considerations mentioned earlier in this document, is a thermal gap pad can be sandwiched between the host PCB and the enclosure wall. The required pad thickness will be slightly thicker than the PCB standoff height to allow for some compression.

The gap pads will ideally be positioned to cover any thermal via arrays, typically these pads will be slightly larger than the thermal via arrays to allow for placement variation. Larger pads will allow for more conduction of heat out of the PCB, but at an additional cost.

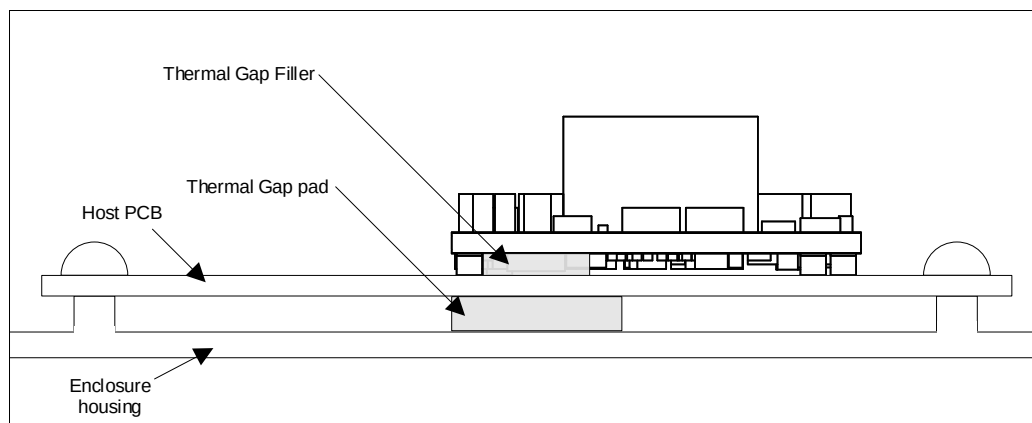


Figure 5: Example Enclosure Heatsinking with an SMT Module

The above solution can be further improved by including a cutout in the region of the host PCB where the thermal Via Arrays would be located, then adding a metal block that is thermally bonded to the metal enclosure wall in this cutout, up to the same height as the host PCB surface. This will allow for the highest power dissipating components to conduct directly into to the enclosure walls without having to pass through the host PCB, reducing the resistance for the thermal energy to the enclosure walls.

This method adds the TIM after assembly so is suitable for both SMT and DIL modules.

Enclosure Wall Heatsinking using Brackets

In some applications, it may not be possible to locate the module alongside an enclosure wall. In these situations, it may be feasible to fabricate a metal bracket that can bridge between the module and the enclosure wall, using the higher thermal conductivity of metal to transmit the thermal energy out of the module into the enclosure walls. This can be used to thermally bond to the transformer of a module or the rear side of a SIL module.

This method will be less effective at reducing the rise in ambient temperatures inside the enclosure when compared to the methods above, due to the fact that some of the thermal energy will radiate out of the bracket into the enclosure air as it passes to the enclosure wall.

Airflow

Air is a poor conductor of thermal energy. Heat absorbed into the air will not be distributed effectively into the surrounding air, creating pockets of heated air surrounding the power dissipating components. Air cooling relies on the heated air to be moved away from the heat source allowing cooler air to absorb the thermal energy.

In applications with no air movement the pockets of heated air encapsulating the components will increase the effective ambient temperature the components are operating in, further increasing the temperature rise of the components.

Silvertel always recommends airflow over the module and other application circuitry.

Cooling by Convection

The simplest and most cost-effective solution for creating airflow in an application is to utilise convection to induce air currents passing over the module and other heat generating components in an application.

This is typically achieved by using ventilation openings in both the top and bottom of an enclosure, See Figure 6. As the air is heated by the components it will tend to rise to be replaced with cooler air from below, if this movement of air is suitably unimpeded with careful enclosure design, a chimney effect can be created creating an air current, pulling fresh air in from the bottom opening and the heated air expelled from the top opening.

This can be very effective in indoor vertical applications, however the openings can make it unsuitable for exterior applications and this method can also be prone to obstructions restricting the air currents when deployed.

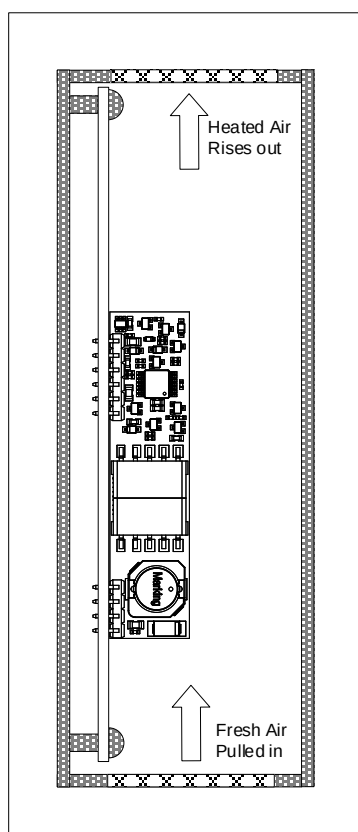


Figure 6: Convection Cooling

Cooling by Forced Air in Unsealed Enclosures

The most common and consistent method of cooling an application is to use a fan or blower to force cool air into the applications enclosure from a ventilation opening. The exhaust can either be through a secondary opening, or allow the exhaust be expelled through the joins in the enclosure panels.

Forced airflow can have a much higher airflow rate than natural convection cooling, which is ideal for smaller more power dense applications that are less affected by mounting orientation and location.

The primary drawbacks of using forced airflow are the cost of the fan or blower, and the addition of a mechanical element into the design of the application that will increase the noise and maintenance requirements of the application. Maintenance requirements can be improved by use of filters to reduce dust build up inside the enclosure.

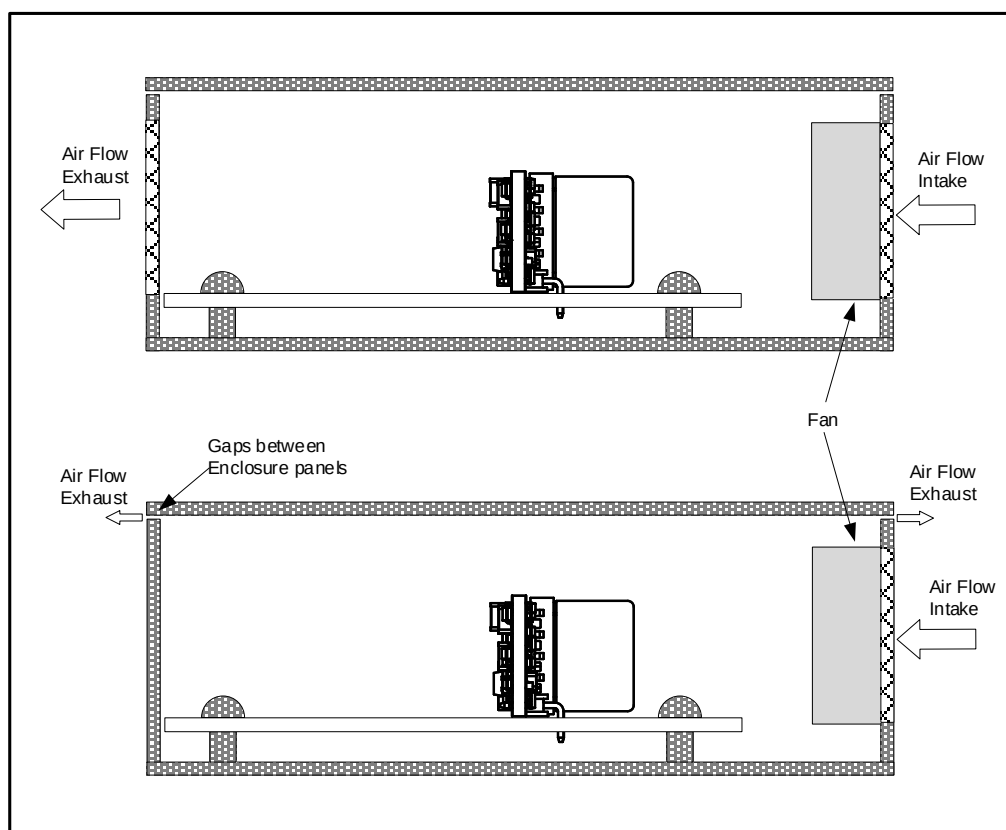


Figure 7: Forced Air Cooling with Ventilation

Cooling by Forced Air in Sealed Enclosure

Sealed enclosures required for providing watertightness can result in the most challenges when it comes to thermal management and it is important consider a combination of solutions.

With no method of air freely passing in and out of the enclosure, the application relies on the enclosure walls absorbing the thermal energy generated inside the enclosure by the application circuitry and dissipating it into the external environment. This can result in elevated temperatures inside the enclosure accelerating the aging of any external components that are temperature sensitive, such as electrolytic capacitors on the output of the module.

Further consideration should be made with sealed enclosure applications that can be located in direct sunlight. Sunlight can considerably elevate the temperature of the walls of an application. This will prevent any thermal energy being dissipated from inside the enclosure until a positive differential between the temperature inside and outside the enclosure has been established. For example, if an applications thermal management solution

results in the ambient temperature inside the enclosure to settle at a temperature 30°C above the enclosure wall, as sunlight raises the temperature of the enclosure walls relative to the outside air temperature, the temperature inside the enclosure will rise until this 30°C temperature differential is reached, this can quickly begin to exceed the maximum operating temperatures of the components within the application.

Reducing the distance the thermal energy has to pass through in air prior to reaching a material with a higher thermal conductivity will increase the rate thermal energy is dissipated into the environment, for this reason, keeping the higher power generating components in close proximity to the enclosure walls and using a material with a high thermal conductivity, such as aluminium, will allow the enclosure walls to absorb the applications thermal energy more readily, reducing the internal ambient temperature inside the application.

Furthermore, use of a fan, or other mechanical means, see Figure 8, to circulate the air inside an enclosure will disperse any pockets of heated air averaging out the air temperature, resulting in more of the warmer air being in contact with the enclosure walls, increasing the effective surface area of enclosure wall that will be conduct the thermal energy.

While there will be a small addition to the total power dissipation of the application from the inclusion of a fan, the increased conduction into the enclosure walls should exceed the additional power usage of a low power fan in all medium to higher power PoE applications.

As this fan is contained within the sealed enclosure, noise will be dampened by the enclosure walls and there will be no dust build up to restrict airflow or contaminate the bearings of the fan.

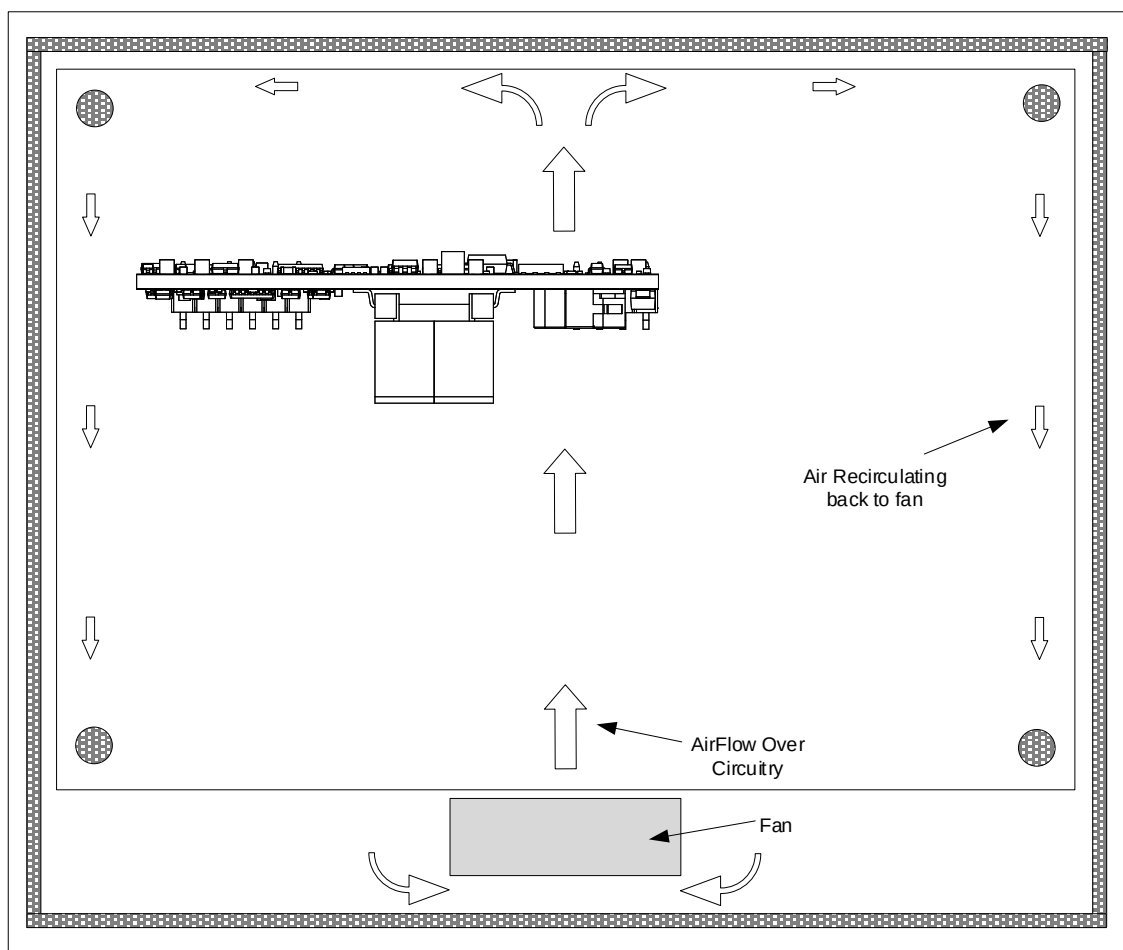


Figure 8: Forced Air Cooling in Sealed Enclosure

Conclusion

As stated at the beginning of this application note, the optimal thermal management solution will be dependent on the applications criteria. The first stage should always be to design an enclosure that promotes airflow and/or conduction to remove the thermal energy from the application circuitry.

The second aspect should be to consider the placement of the power dissipating components such as a Silvertel PoE module, such that heat planes with thermal vias can be implemented, with consideration for implementing additional thermal management solutions if testing later reveals further measures are required. This may involve positioning a SIL module adjacent to the enclosure wall. If the application requires a sealed enclosure, relying on conducting into the enclosure walls for its thermal management, it is recommended that the highest power generating components are dispersed across the PCB to prevent heat saturation slowing the transfer of thermal energy away from the module.

It is not possible to provide a figure for the thermal conductivity required for an application as it will be dependent on the applications load power and profile, the coverage area of the material, and the rate the thermal energy needs to be removed from the application. None of Silvertel's products require a TIM to be applied to them for operation, but in applications where a module has a sustained high load, thermals can be easier managed with the application of a TIM.

The information covered in this document is designed to provide a guide to the thermal management options available to different applications. Testing should be performed to confirm the chosen thermal management solution allows the application to operate as expected across the range of required operating environmental conditions that an application is being designed for.

We hope you have found the information detailed in this document useful. We would be happy to discuss anything included, or any other technical related questions at any time. Please contact apps.support@silvertel.com.