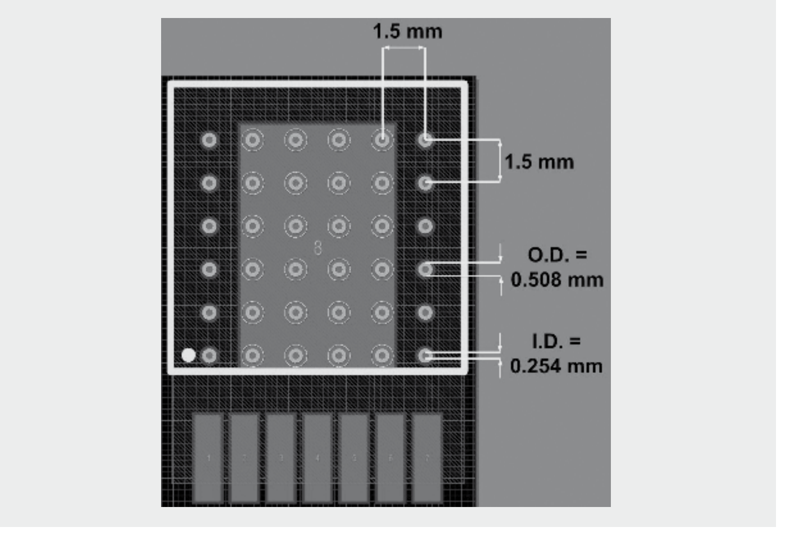

Fig. 3.10: Placement of thermal vias

3.3 Filtering

Input filter

3.3.1 Input filter

Depending on the circuit topology, switching regulators generate conducted EMI noise related to the alternating current components in their leads. Würth Elektronik MagI³C power modules are optimized for low conducted noise and radiated interference and the ripple is negligible. An output filter is therefore not absolutely essential for most applications.

The AC component of the input current can cause radio frequency interference depending on the areas of application and use. In the above case, it is the designer's responsibility to check whether they intend to have an input filter on the power module or at another point in their circuit.

Switching frequency

ESR

Differential mode voltage

How does the noise arise and what can you do to reduce it? Due to the switching of a buck converter, a pulsating current flows in the input circuit with the switching frequency of the module clock. The AC component of this current is delivered from the input capacitor. Depending on the size of the equivalent series resistance (ESR) of the capacitor, a ripple is superimposed on the DC current that results in an unwanted voltage drop at the capacitor, as well as at the lead impedances. This differential mode interference voltage is partly visible in the conducted interference emission measurement.

The more critical interference signal in EMI is common mode noise or CM. The reason for this is the rapid change in the switch node potential in relation to the earth potential. Together with parasitic capacitances, such as between the heat sink of the switching transistor and the device case and on to earth, the voltage change is the

Common mode voltage

source of a common mode current and can be measured (see chapter 3.6). The faster the semiconductor components in the switching converter switch (blocking/conducting), the higher is the interference potential.

LC input filter

The unwanted noise level of the input current can be reduced with a LC filter at the input of the converter to a level below the limit set by international standard. Even if an EMC filter is present on a device with AC voltage input on the AC side of the first switching power supply, an additional filter may be necessary at the input of each downstream DC/DC switching converter.

A filter consisting of an inductor and a capacitor theoretically attenuates about 40 dB/decade in the blocking frequency range. Parasitic properties of the filter component reduce this value, however. A cut-off frequency f_{co} is chosen to dimension the filter, which is well below the clock frequency of the power module. A common value is one tenth of the switching frequency of the converter:

$$f_{co} = \frac{f_{sw}}{10} \tag{3.1}$$

The cut-off frequency of an LC low-pass filter corresponds to the resonant frequency of a series resonant circuit.

$$f_{co} = \frac{1}{2\pi \cdot \sqrt{L_f \cdot C_f}} \tag{3.2}$$

If the component, e.g. the filter inductor, is selected for its electrical parameters (inductance, rated current, DC resistance), the second filter component capacitor's value can be calculated as:

$$C_f = \frac{1}{(2\pi \cdot 0{,}1 \cdot f_{sw})^2 \cdot L_f} \tag{3.3}$$

The filter capacitor can be at the same time the input capacitor of the switching regulator. It has to be configured such that it meets the requirement for the AC component of the module input current in order to avoid excessive heating of the component. The ESR is the most important factor here. The higher the value, the greater the power losses in the capacitor. Due to their construction, liquid electrolyte capacitors have a higher ESR than solid electrolyte and ceramic capacitors. If a capacitor with low ESR is used, there is, however, the risk that the regulatory circuit starts to oscillate with changes in load or input voltage. This is due to the high quality factor, Q of the input filter, which, especially at the filter resonant frequency, means that the output impedance of the LC filter exceeds the input impedance of the switching regulator in terms of its magnitude. The quality factor of the input filter can be reduced by connecting a network of resistance (R_d) and Capacitance (C_d) in series. Hence the output impedance can be reduced. The attenuation resistance (R_d) is calculated as follows:

$$R_d = \sqrt{\frac{L_f}{C_f}} \quad (3.4)$$

The capacitance of the attenuation capacitor should be many times that of the filter capacitor. In practice, a value is selected according to the following model:

$$5 \cdot C_f \leq C_d \leq 10 \cdot C_f \quad (3.5)$$

Alternatively, a single electrolytic capacitor can be connected across the filter capacitor as a replacement of the attenuation RC network. If the supply network impedance is high, a further filter capacitor may be necessary in front of the inductor (Π filter).

Output Filter

3.3.2 Output filter

The MagI³C power modules from Würth Elektronik have a very low voltage output ripple and for this reason an output filter is usually not necessary. In applications such as power supply to sensitive A/D converters, sensor lines, analog switching circuits or radio modules, an output filter will reduce the ripple to a minimum or suppress harmonic oscillations. The sizing of the filter can be undertaken as already described for the LC input filter. Additional attenuation of the filter is not necessary at this point.

3.4 Heat management

The major contributors of power losses in DC/DC converters are switching losses and conduction losses. This is transformed into heat and, in conjunction with the ambient temperature, has a great influence on the lifetime of a switching regulator and thus on the application. Therefore, as described in Chapter 3.2, appropriate heat removal has to be ensured.

3.4.1 Efficiency

Efficiency

Efficiency is a dimensionless parameter (values between 0 and 1) and describes the ratio between the output and input power (power losses). The value η is usually specified in percent. As the input power is never the same as the output power, the ideal efficiency of 1 or 100% is never attained.

$$\text{Efficiency } (\eta) = \frac{P_{out}}{P_{in}} \quad (3.6)$$