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Heatsink

In the buck converter part of the circuit, we used two heatsinks with different thermal resistances for the low side and high side MOSFETs. After completing the thermal analysis, we noticed that we must use heatsinks for MOSFETs. Then, we calculated the required thermal resistance to achieve maximum junction temperatures (150°C). When we select the heatsinks, we paid attention to the volumes of heatsinks and of course their thermal resistances.

* For the high side MOSFET, we have decided to use V-1100-SMD/B-L heatsink that has 25 °C/W thermal resistance:

**Link:** <https://www.digikey.com/en/products/detail/assmann-wsw-components/V-1100-SMD-B-L/3511509>

* For the low side MOSFET, we have decided to use 573100D00000G heatsink that has 15 °C/W thermal resistance:

**Link:** <https://www.digikey.com/en/products/detail/aavid-thermal-division-of-boyd-corporation/573100D00000G/1625595>

# Power Losses

In this part of the report, firstly we will state losses on the diodes and MOSFETs, then we will calculate them.

## Diode Losses

In diodes there are two main losses. They are conduction and reverse recovery losses.

## Conduction Losses

Conduction losses are simply product of forward voltage of diode and average current flowing through it. It is found by Equation 4:

[4]

Conduction losses are observed when diode is conducting current. Our diode has forward voltage of 1.1 V. Also, we observed that average current passing through it 0.5 A. Thus, we find conduction loss:

## Reverse Recovery Losses

When diode is in reverse biased mode, carriers are moved out from the layer until the current in the forward direction becomes zero. At that time, reverse current flows through the diode. It is also called recovery current. This current causes reverse recovery losses. It is found by Equation 5:

[5]

Where

Reverse voltage (V)

Switching frequency (Hz)

Reverse recovery charge (C)

Reverse recovery time (sec)

Reverse recovery current (A)

We observed that reverse voltage on the diodes are around 260 V from the simulation results. We took switching frequency as 100 kHz in the simulation. Diode we chose has reverse recovery charge that can be seen from the datasheet. Thus, reverse recovery loss is calculated:

As a result, losses on a diode:

Since we have six diodes in the design, total losses on the diodes:

## MOSFET Losses

In MOSFETs there are two main losses. They are conduction and switching losses.

## Conduction Losses

Conduction losses of MOSFETs are simply product of drain to source on resistance of MOSFET and average current flowing through it. Since we used synchronous buck converter in our design, conduction losses of low side and high side MOSFETs are calculated separately. Conduction loss of low side and high side MOSFETs are calculated by Equation 6 and 7:

[6]

[7]

Where

Conduction loss of low side MOSFET (W)

Conduction loss of high side MOSFET (W)

Drain to source on resistance of MOSFET (Ω)

Average current passing through MOSFET (A)

Duty cycle

We observed from the datasheet that our MOSFETs have 1.15 Ω drain to source on resistance Also average current passing through it and average duty cycle of our design are 2.5 A and 20%, respectively. Thus, conduction loss of low side and high side MOSFETs are calculated:

## Switching Losses

As MOSFET switches turn on and off, energy is dissipated due to parasitic effects (rise and fall time). This type of loss is called switching losses. Switching losses of high side and low side MOSFETs are calculated by Equation 8 and 9:

[8]

[9]

Where

Input voltage (V)

Forward voltage of low side MOSFET body diode (V)

Average current passing through MOSFET (A)

Turn on rise time (sec)

Turn off fall time (sec)

Switching frequency (Hz)

For high side MOSFET, in our design, is around 120 V. Also, as we mentioned before, average current passing through MOSFET is 2.5 A. Also, and values of the MOSFET are 22ns and 20ns, respectively. As a result, switching loss of high side MOSFET is calculated:

For low side MOSFET, in our design, is around 0.9 V. We observed this value from the reverse current vs body diode voltage graph in its datasheet. Also, as we mentioned before, average current passing through MOSFET is 2.5 A. Also, and values of the MOSFET are 22ns and 20ns, respectively. As a result, switching loss of low side MOSFET is calculated:

Total power loss of low side MOSFET:

Total power loss of high side MOSFET:

# Thermal Analysis

In this part of the report, thermal analysis for diodes and MOSFET will be done. Firstly, we will analyze without heatsink. Then, if temperature exceeds the range for diodes and MOSFETs, we will state heatsink requirements. Finally, we will analyze (if required) the temperature with selected heatsinks.

## Diode Thermal Analysis

We calculated losses of one diode First, thermal analysis for a diode without heatsink is calculated by Equation 10:

[10]

Where

Junction temperature of the diode

Ambient temperature (25°C)

Power loss of the diode

Thermal resistance, junction to ambient (°C/W)

We observed from datasheet of the diode that the diode has junction to ambient thermal resistance of 53 °C/W. Junction temperature of the diode is calculated:

The diode can operate between temperatures of -65°C and +150°C. 124.375°C is consistent with this temperature range. As a result, heatsink is not needed for the diodes.

## MOSFETs Thermal Analysis

In this part, we will analyze the temperature of high side and low side MOSFETs separately.

## High Side MOSFET

From power losses part, we calculated power losses of high side MOSFET as 2.0675 W. First, thermal analysis for high side MOSFET without heatsink is calculated:

In this calculation, we took ambient temperature as 25°C. Also, the MOSFET has junction to ambient thermal resistance of 110°C/W. The MOSFET can operate between temperatures of -55°C and +150°C. We calculated junction temperature 252.42°C without heatsink. This value is out of operating junction temperature range, so we must use heatsink for high side MOSFET.

Required thermal resistance to achieve maximum 150°C junction temperature at 25°C ambient is calculated by Equation 11:

[11]

Thermal resistance, junction to case (°C/W)

Thermal resistance of heatsink (°C/W)

The MOSFET has junction to case thermal resistance of 1.4°C/W. Required maximum heatsink thermal resistance is found:

That is, heatsink we will select must satisfy .

We have decided to use V-1100-SMD/B-L heatsink because it is not expensive and has small volume with respect to others. It has 25 °C/W thermal resistance consistent with the requirements. As a result, junction temperature with heatsink is found:

## Low Side MOSFET

From power losses part, we calculated power losses of low side MOSFET as 5.7547 W. First, thermal analysis for high side MOSFET without heatsink is calculated:

In this calculation, we took ambient temperature as 25°C. Also, the MOSFET has junction to ambient thermal resistance of 110°C/W. The MOSFET can operate between temperatures of -55°C and +150°C. We calculated junction temperature 658.017°C without heatsink. This value is out of operating junction temperature range, so we must use heatsink for low side MOSFET.

Required thermal resistance to achieve maximum 150°C junction temperature at 25°C ambient is calculated by Equation:

[12]

Thermal resistance, junction to case (°C/W)

Thermal resistance of heatsink (°C/W)

The MOSFET has junction to case thermal resistance of 1.4°C/W. Required maximum heatsink thermal resistance is found:

That is, heatsink we will select must satisfy .

We have decided to use 573100D00000G heatsink. It is more expensive than heatsink for high side MOSFET. On the other hand, it has small volume with respect to others. Heatsinks for high side and low side MOSFETs are almost same volume. It has 15 °C/W thermal resistance consistent with the requirements. As a result, junction temperature with heatsink is found: