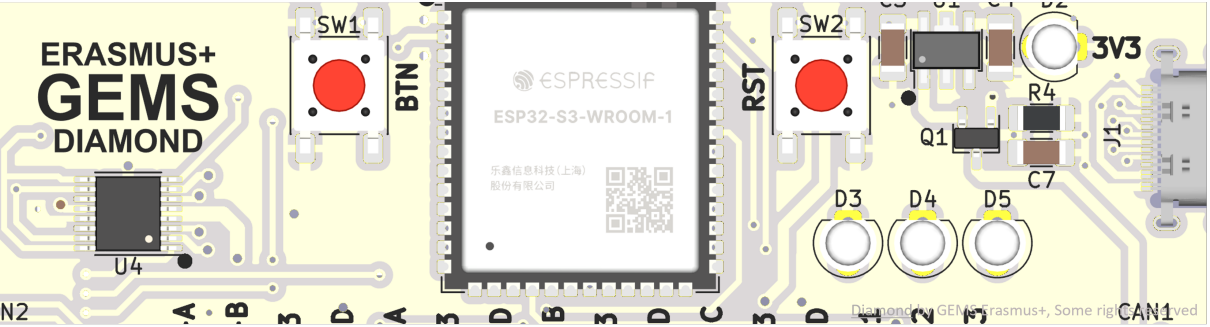


# Tutorial 3

## Losses in a Motor Drive

**Dr. ir. Sachin Yadav**
DCE&S, ESE, TU Delft

TU Delft

1. Motor Drive - Operation and Losses
2. Example - DRV8411
3. Thermals

1. Motor Drive - Operation and Losses
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# Operating modes

$\omega \propto V_{12} \propto D$
$D$ is changed through half bridges ($S_1$ & $S_2$ and $S_3$ & $S_4$)
Two modes:

- High-side recirculation
- Low-side recirculation

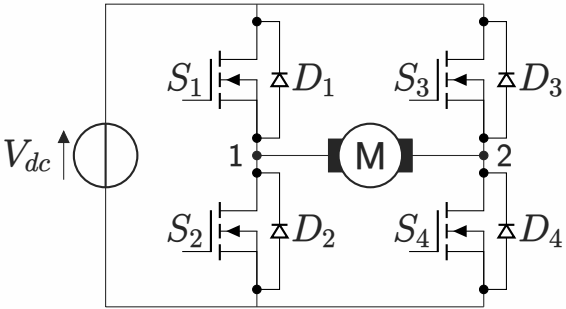
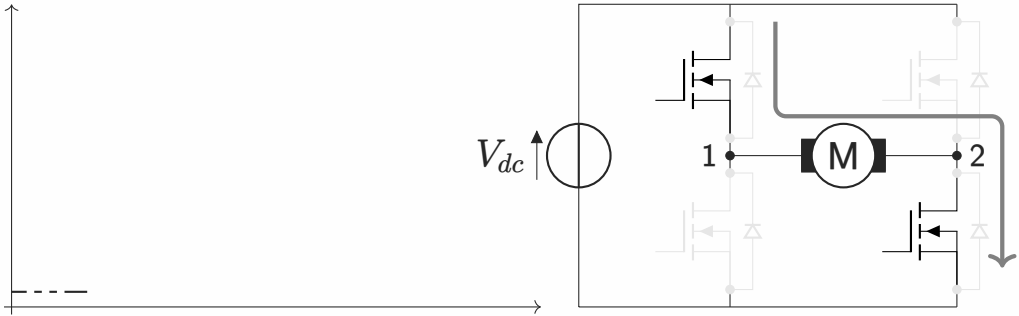



**Figure:** DC motor drive.

# Power losses in motor drive

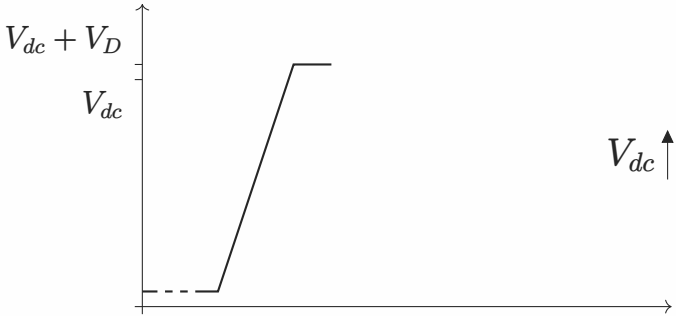
High side recirculation - voltage at point 2:

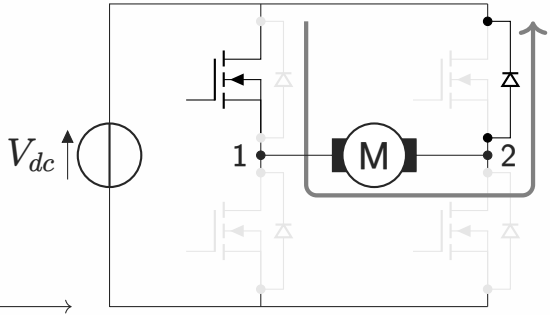



$$P_{loss} = P_{cond,S1} + P_{cond,S4}$$

# Power losses in motor drive

High side recirculation - voltage at point 2:

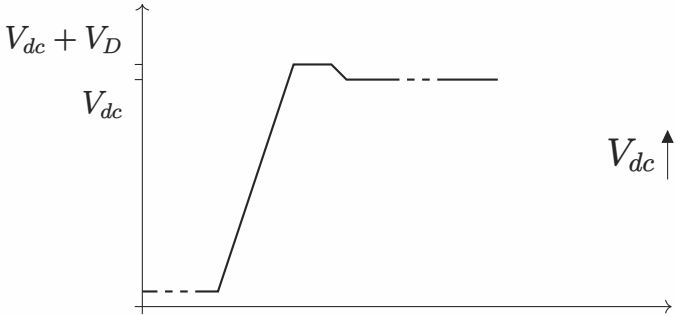


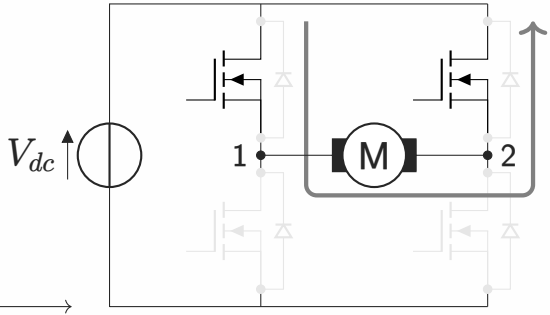




$$P_{loss} = P_{cond,S1} + P_{sw,S4} + P_{cond,D3}$$

# Power losses in motor drive

High side recirculation - voltage at point 2:

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# Power losses in motor drive

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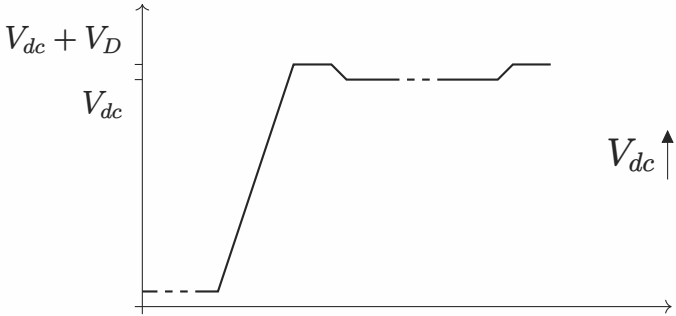


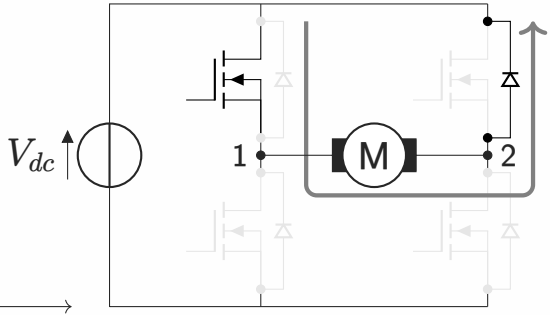


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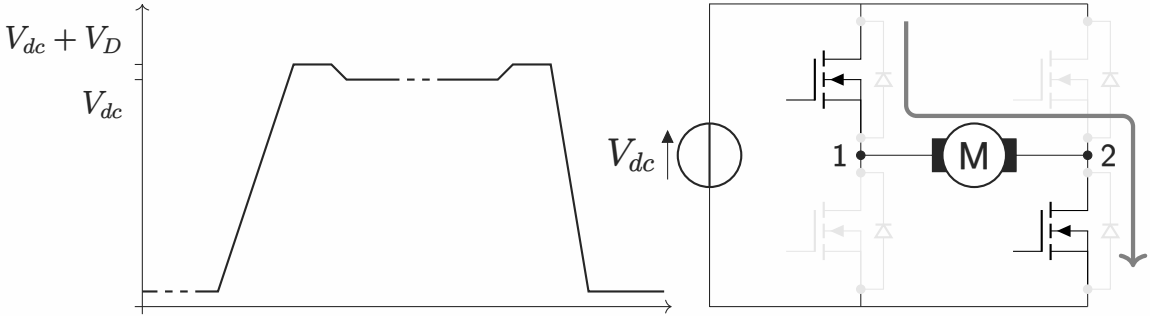
# Power losses in motor drive

High side recirculation - voltage at point 2:




$$P_{loss} = P_{cond,S1} + P_{sw,S4} + P_{cond,S4}$$

1. Motor Drive - Operation and Losses
2. Example - DRV8411
3. Thermals

# DRV8411

The DC motor driver is used in the GEMS Diamond board.

- Two H-bridges

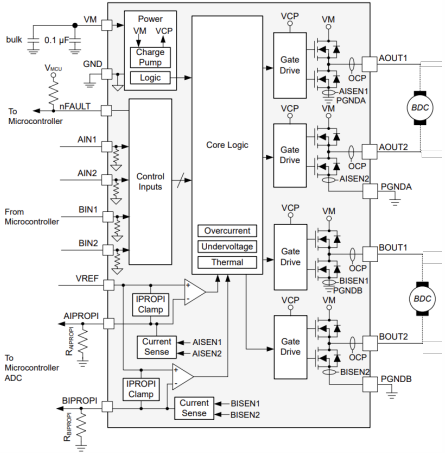



**Figure:** Functional block diagram of DRV8411 [1].

# DRV8411

The DC motor driver is used in the GEMS Diamond board.

- Two H-bridges
- Outputs are connected in parallel

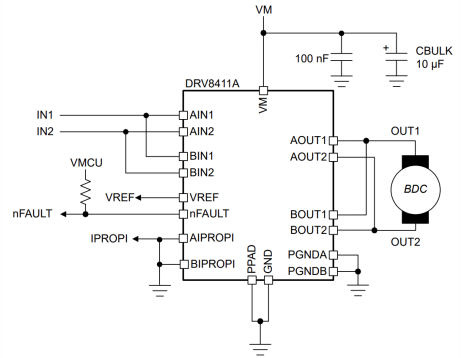



**Figure:** Connection in Diamond board [1].

# DRV8411

The DC motor driver is used in the GEMS Diamond board.

- Two H-bridges
- Outputs are connected in parallel
- Same PWM signals for corresponding switches in two H-bridges

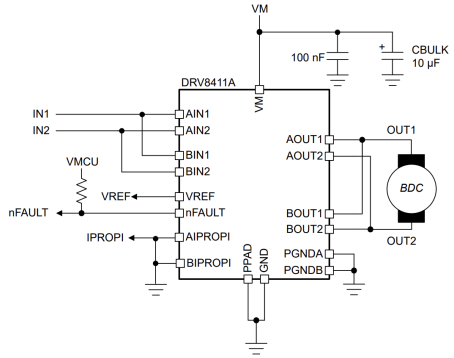



**Figure:** Connection in Diamond board [1].

# Loss parameters

**Table:** DRV8411 switch parameters.

| Symbol | Value |
|---|---|
| $R_{HS-DS,on}$ | 200 mΩ @ $I_L = 0.2$ A |
| $R_{LS-DS,on}$ | 200 mΩ @ $I_L = -0.2$ A |
| $V_{SD}$ | 1 V @ $I_L = -0.5$ A |
| $t_{rise}$ | 100 ns @ $V_{dc} = 5$ V |
| $t_{fall}$ | 50 ns @ $V_{dc} = 5$ V |
| $t_{dead}$ | 400 ns |

**Table:** Operating parameters.

| Symbol | Value |
|---|---|
| $V_{dc}$ | 4.2 V |
| $D$ | 0.5 |
| $I_L$ | 0.2 A |
| $f_{PWM}$ | 5 kHz |

# Loss calculation

- Conduction losses:
  $P_{cond,S1} = 0.5 I_L^2 R_{HS-DS,on} = 4$ mW
  $P_{cond,S2} = 0$ W
  $P_{cond,S3} = 0.5 D I_L^2 R_{HS-DS,on} = 2$ mW
  $P_{cond,S4} = 0.5(1-D) I_L^2 R_{LS-DS,on} = 2$ mW

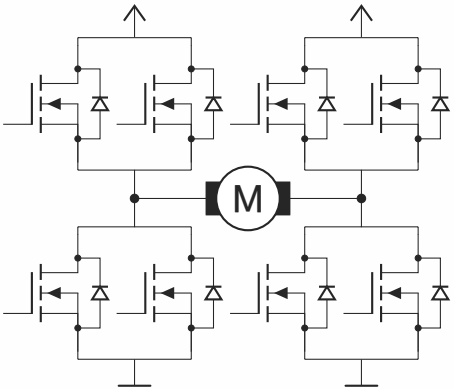



**Figure:** DRV8411 motor drive switch configuration.

# Loss calculation

- Switching losses:
  $P_{sw,S1} = 0$
  $P_{sw,S2} = 0$
  $P_{sw,S3} = 0$
  $P_{sw,S4} = 0.5 V_{dc} I_L t_{rise} f_{PWM}$
  $+0.5 V_{dc} I_L t_{fall} f_{PWM} = 0.315$ mW

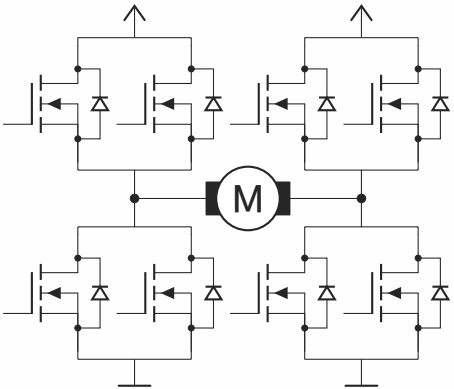



**Figure:** DRV8411 motor drive switch configuration.

# Loss calculation

- Diode conduction losses:
  $P_{cond,D1} = 0$
  $P_{cond,D2} = 0$
  $P_{cond,D3} = 2V_{DC}I_L t_{dead} f_{PWM}$
  $= 3.36$ mW
  $P_{cond,D4} = 0$

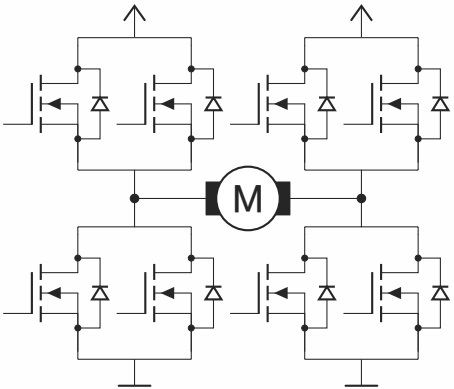



**Figure:** DRV8411 motor drive switch configuration.

# Loss calculation

- Other negligible losses:
  - Gate driver losses
  - Device consumption losses
  - In some chips: LDO regulator losses

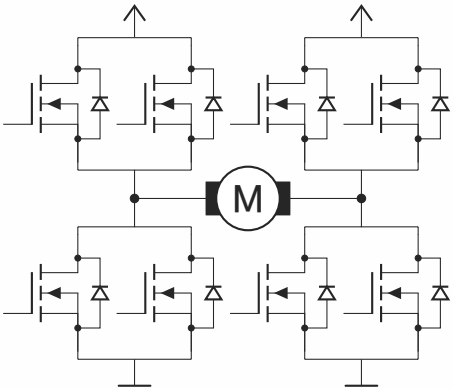



**Figure:** DRV8411 motor drive switch configuration.

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# Heat dissipation mechanisms

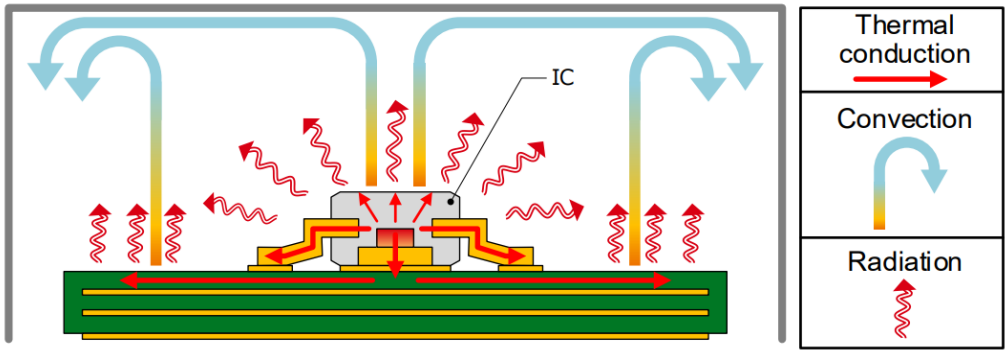


**Figure:** Heat dissipation mechanisms. Source: [2].

# Semiconductor thermal parameters

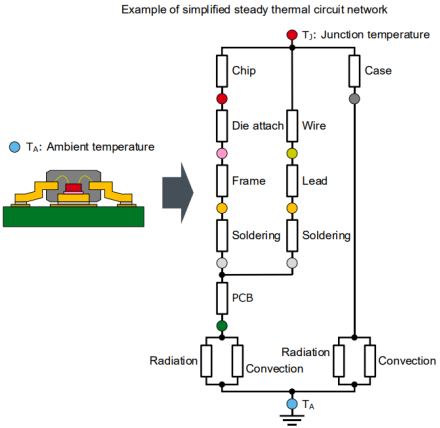


**Figure:** Heat dissipation parameters. Source: [2].

# DRV8411

**Table:** Thermal data for DRV8411

| Symbol | Description | Value |
|---|---|---|
| $R_{\theta JA}$ | Junction-to-ambient thermal resistance | 45.1 °C W$^{-1}$ |
| $R_{\theta JC(top)}$ | Junction-to-case (top) thermal resistance | 43.7 °C W$^{-1}$ |
| $R_{\theta JB}$ | Junction-to-board thermal resistance | 19.9 °C W$^{-1}$ |
| $R_{\psi JT}$ | Junction-to-top characterization parameter | 2.6 °C W$^{-1}$ |
| $R_{\psi JB}$ | Junction-to-board characterization parameter | 19.9 °C W$^{-1}$ |
| $R_{\theta JC(bot)}$ | Junction-to-case (bottom) thermal resistance | 4.9 °C W$^{-1}$ |

# DRV8411

Total IC losses calculated previously: 11.675 mW.

- How to calculate the temperature rise?

# DRV8411

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- How to calculate the temperature rise?
  $T_{rise} = R_{\theta xy} P_{loss}$

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- How to calculate the temperature rise?
  $T_{rise} = R_{\theta xy} P_{loss}$
- Which thermal parameters ($R_{\theta xy}$) to use?

# DRV8411

Total IC losses calculated previously: 11.675 mW.

- How to calculate the temperature rise?
  $T_{rise} = R_{\theta xy} P_{loss}$
- Which thermal parameters ($R_{\theta xy}$) to use?

- Depends upon the main power sinks!
- Some parameters are not applicable. For e.g. $R_{\theta JA}$.

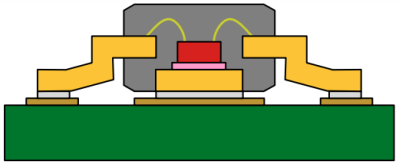
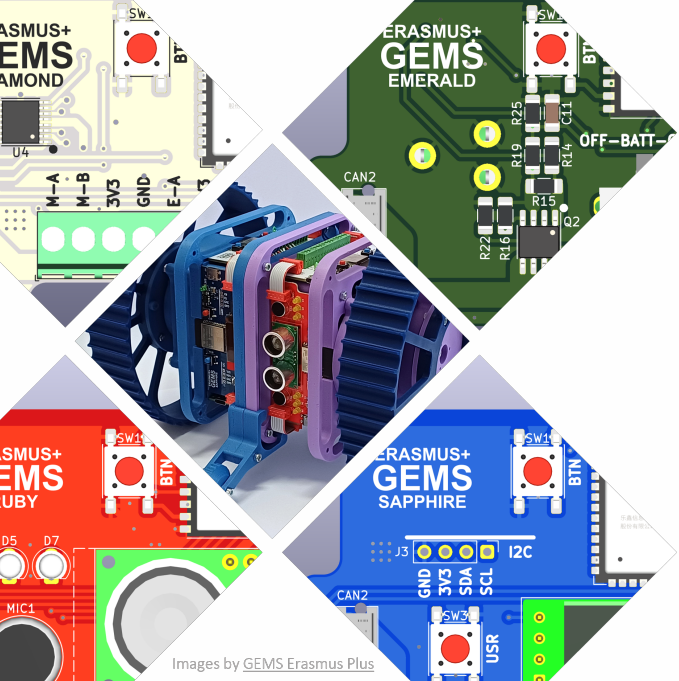


**Figure:** IC package. Source: [2].

# Conclusion

- Converter operating modes, and power losses.
- DRV8411 application and loss calculation.
- Thermal dissipation.




Images by GEMS Erasmus Plus

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[1] T. Instruments. *DRV8411A Dual H-Bridge Motor Driver with Current Regulation datasheet (Rev. B)*. July 2024. URL: https://www.ti.com/lit/ds/symlink/drv8411a.pdf.

[2] R. Semiconductor. *Basics of Thermal Resistance and Heat Dissipation*. Aug. 2021. URL: https://fscdn.rohm.com/en/products/databook/applinote/common/basics_of_thermal_resistance_and_heat_dissipation_an-e.pdf.