UM3661

User manual

Getting started with AutoDevKit configurable DC motor driver boards

Introduction

A rapidly expanding trend in vehicles is the development of body electronics, which enhances occupant comfort and convenience by allowing easy adjustment of various settings. These systems range from common features in most cars to advanced options in premium models and include access systems for secure entry and exit. Additionally, automotive safety is a major focus, with integrated systems such as active restraints, passive safety measures, and vibration management improving occupant protection and driving comfort.

Seatbelt pretensioners are vital safety devices that tighten the seatbelt instantly during a crash, removing slacks and securing occupants in the best position within milliseconds. Most modern vehicles use pyrotechnic pretensioners activated by an explosive charge, often integrated with airbag systems. Different types, such as retractors, buckles, and anchor pretensioners, work together to prevent passengers from sliding under the belt. These single-use devices must be replaced after deployment, usually indicated by a locked belt and warning light. Advanced systems can tighten belts during pre-crash events and release if no collision occurs.

Central door lock systems automatically unlock all doors upon crash detection to aid rescue efforts, triggered by sensors like G-switches or supplemental restraint systems. This activation also switches on interior lights and hazard signals. Small motors in each door reverse the locking mechanism to unlock during emergencies. Key safety features include pre-crash activation, where pretensioners work with driver assistance systems to brace occupants early, and load limiters that release some belts to reduce chest force after pre-tensioning. The crash-unlock system operates alongside airbag deployment to ensure passengers can exit safely.

Engine vibration compensation systems improve driving comfort and reduce wear by managing torsional vibrations and sudden torque changes that cause driveline jerking. Components like dual-mass flywheels and harmonic balancers help, while advanced solutions include electronically controlled mounts and active torque management in the ECU. These systems reduce noise, vibration, and harshness by decoupling the engine from the vehicle's body.

The AEK-MOT-8DCMH98 and AEK-MOT-4DCMH94 evaluation boards perfectly fit in this market, as they are designed to drive brushed DC motors for various body control and convenience applications like seat control, steering adjustment, sunroof, sliding doors, windows, and washer pumps. It also supports safety features such as seatbelt pretensioners and central door lock systems, as well as chassis and powertrain functions like engine vibration compensation. The AEK-MOT-8DCMH98 is based on the L99MH98 octal half-bridge pre-driver, and can control eight configurable channels, driving up to four bidirectional motors simultaneously with high current capacity.

The AEK-MOT-4DCMH94, instead, is based on the L99MH94 and can control four configurable channels, driving up to 2 bidirectional motors.

The boards offer flexible configurations, including driving resistive loads and sequential motor control. They support two current measurement methods: a traditional sensing resistor and an innovative indirect MOSFET-based method that reduces cost and complexity. Control is managed via a 24-bit SPI interface, providing detailed diagnostics like voltage, temperature, and fault monitoring.

Advanced protection features ensure compliance with ISO 26262 ASIL-B safety standards, including short-circuit detection, overtemperature shutdown, and watchdog timers. The boards perform off-state diagnostics to detect faults without stressing components and alerts the microcontroller immediately upon failure. Reverse polarity protection and configurable safety watchdogs enhance robustness. They connect easily to microcontroller boards through a 96-pin automotive unified connector for communication and sensing.

Warning: *The evaluation boards described in this user manual are designed for R&D laboratory use only. They are not intended for field use in vehicles. Moreover, they are not a reference design. Their purpose is evaluation and not production as stated in our Terms of use.*

Figure 1. AEK-MOT-8DCMH98 evaluation board

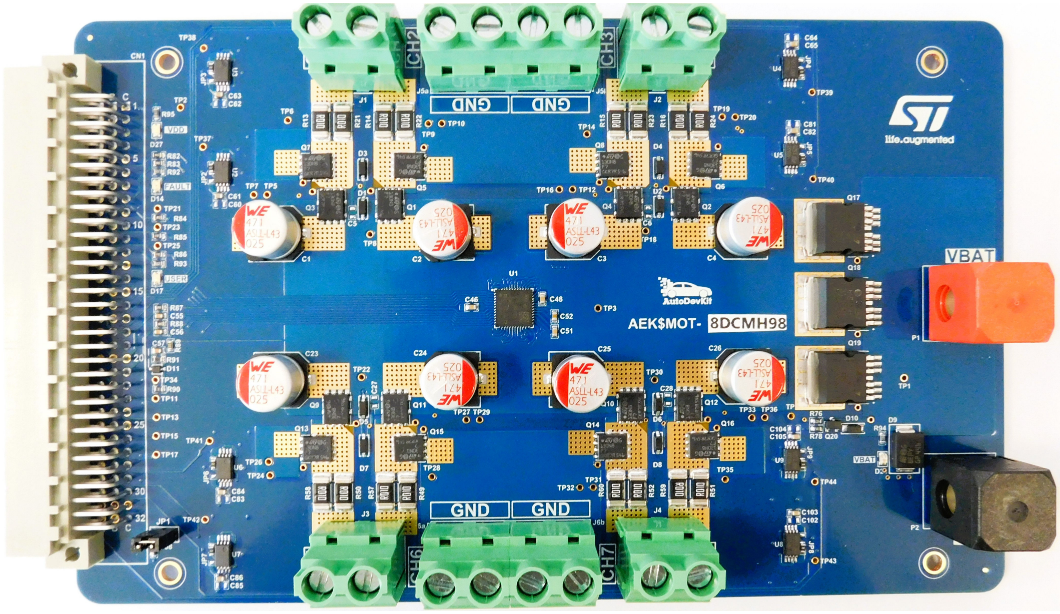
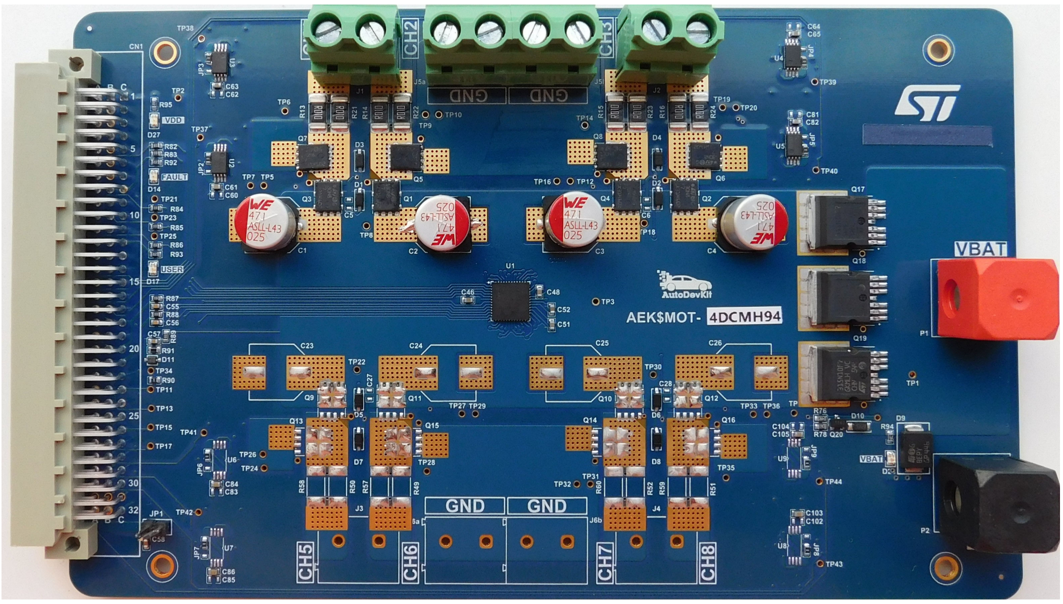


Figure 2. AEK-MOT-4DCMH94 evaluation board

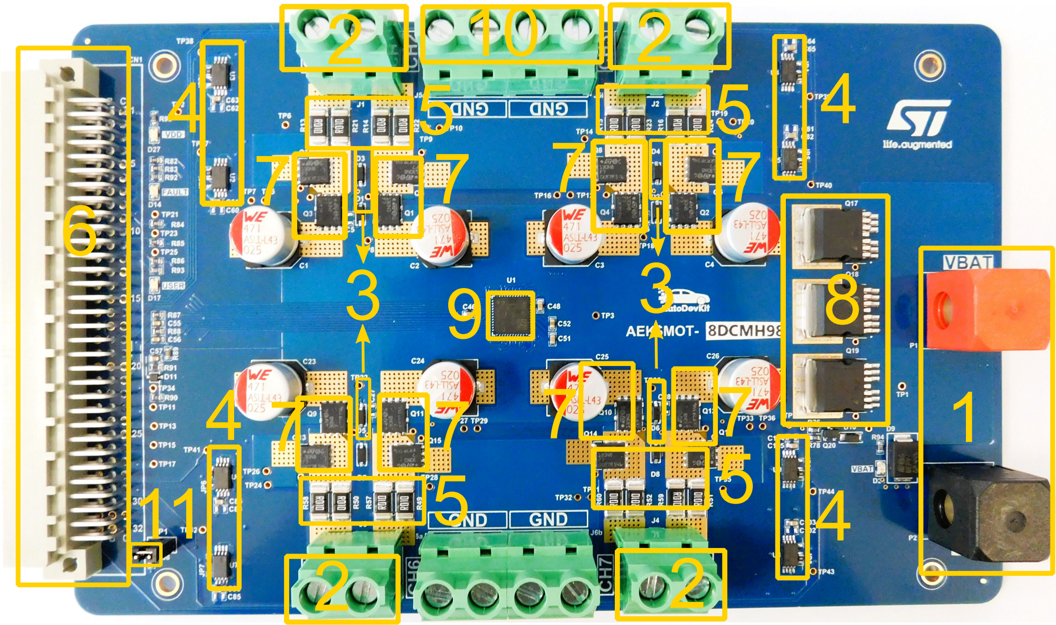


Note: For dedicated assistance, please submit a request to our AutoDevKit Community.

1 Hardware overview

1.1 AEK-MOT-8DCMH98 main components

Figure 3. **AEK-MOT-8DCMH98 evaluation board, top view: main components**



1. *12 V DC power supply connector*
2. *Connector for DC motors*
3. *Indirect current sensing circuitry to measure the MOSFET area temperature*
4. *External current sensing circuitry to measure direct current loads*
5. *R_{SENSE} for the current sensing networks*
6. *Standardized 96-pin plug-and-play automotive unified connector to plug MCU boards (for example, AEK-MCU-C4M3 belonging to the AEK-MCU-C4MLIT3 evaluation kit)*
7. *External MOSFETs for full bridge/half-bridge configuration*
8. *External reverse battery protection circuitry*
9. *L99MH98 octal half-bridge, or quad H-bridge, pre-driver for DC motors in automotive applications*
10. *GND auxiliary connector*
11. *Vbat to 12V_ext jumper (JP1)*

1.1.1 L99MH98 main board-hosted device

L99MH98 is an integrated octal half-bridge pre-driver controlling up to sixteen N-channel MOSFETs.

It is intended for DC motor control applications such as automotive power seat control or other applications.

A 24-bit serial peripheral interface (SPI) is used for configuring and controlling the eight half-bridges or four H-bridges. SPI status registers provide high-level diagnostic information such as supply voltage monitoring, the charge pump voltage monitoring, temperature warning, and overtemperature shutdown.

Each gate driver independently monitors its external MOSFET drain-source voltage for fault conditions.

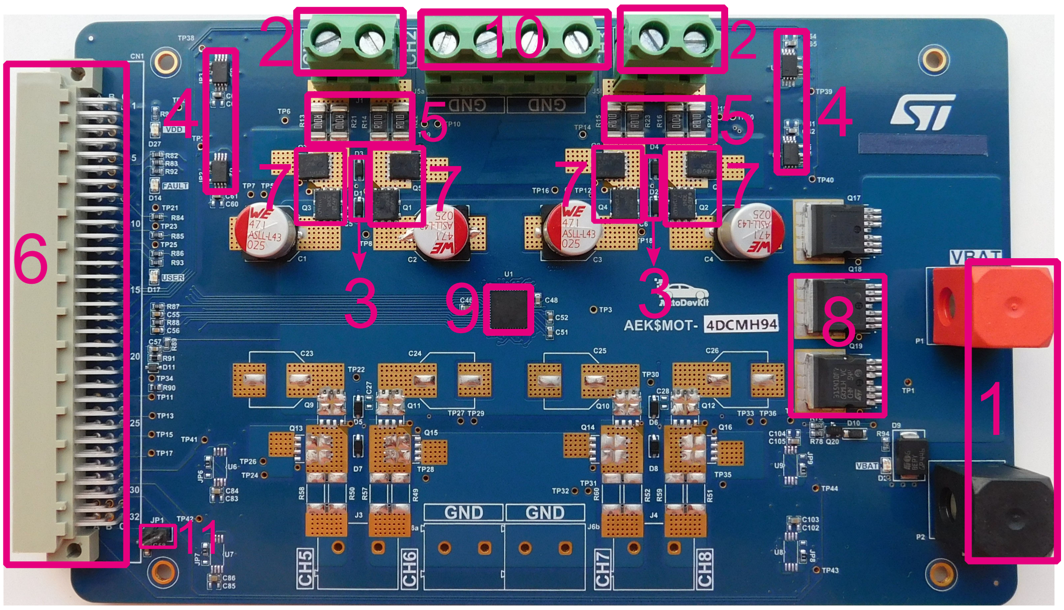
The L99MH98 supports indirect current measurement on external MOSFETs, allowing cost saving and lower system complexity, avoiding the usage of shunt resistors.

A more efficient gate current control of the external MOSFETs, called “three stages gate current”, decreases and optimizes electromagnetic interference (EMI).

Protection features (drain-source monitoring for short circuit detection, overtemperature warning and shutdown, timeout watchdog for MCU control, detailed off-state diagnostic via SPI) ensure the ASIL-B level achievement according to ISO 26262 standard.

1.2 AEK-MOT-4DCMH94 main components

Figure 4. AEK-MOT-4DCMH94 evaluation board, top view: main components



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10. *GND auxiliary connector*
11. *Vbat to 12V_ext jumper (JP1)*

1.2.1 L99MH94 main board-hosted device

The L99MH94 is an integrated quad half-bridge pre-driver dedicated to control up to eight N-channel MOSFETs.

It is intended for DC motor control applications such as automotive power seat control or other applications.

A 24-bit serial peripheral interface (SPI) is used for configuring and controlling the eight half-bridges or four H-bridge. SPI status registers provide high-level diagnostic information such as supply voltage monitoring, the charge pump voltage monitoring, temperature warning and overtemperature shutdown.

Each gate driver monitors independently its external MOSFET drain-source voltage for fault conditions.

The L99MH94 supports indirect current measurement on external MOSFETs, allowing cost saving and lower system complexity, avoiding the usage of shunt resistors.

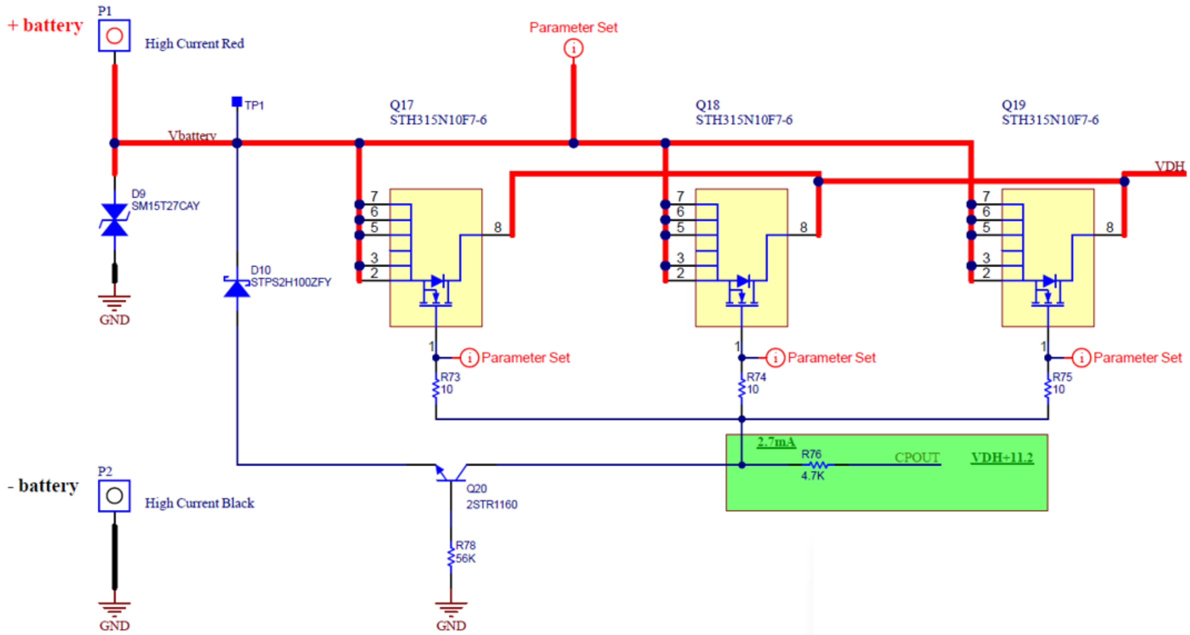
A more efficient gate current control of the external MOSFETs, called “three stages gate current”, decreases and optimizes electromagnetic interference (EMI).

Protection features (drain-source monitoring for short circuit detection, overtemperature warning and shutdown, timeout watchdog for MCU control, detailed off-state diagnostic via SPI) ensure the ASIL-B achievement according to ISO 26262 standard.

1.3 External reverse battery protection

External reverse battery protection represents robust protection for the electrical system. The danger that all electrical systems face is reversed polarity from the power source. This can be caused by a short circuit or, more often, by simply switching the power and ground terminals when connecting a power supply. This can lead to several damages if the system is not protected.

Figure 5. Reverse battery protection



In nominal conditions, since the gate voltage is not higher than the source voltage (in this case, V_{BAT} that is usually 12 V) the NMOS cannot turn on (i.e. $V_G > V_S$). To allow conduction of the supply voltage, a charge pump (CPOUT) supplies an additional voltage that ensures a gate voltage greater than the source voltage, switching the NMOS on (i.e. VG = VDH+12 V), when the charge pump is on. So, we have V_G = VDH+12 V > V_S.

Reverse protection

If the supply voltage is reversed (that is, the polarity of the power source is reversed), the bipolar junction transistor (BJT) puts the NMOS gate to GND. When the power source is correctly connected, the base voltage is lower than the collector-emitter voltage and then the BJT is turned off.

So, in the case of reverse polarity, the power source creates a positive voltage between the emitter and the base. This voltage conducts the BJT that will put the NMOS gate to GND. The D10 diode and the R78 resistor have the function, respectively, to block the current input to the BJT under normal operation and to limit the current at the BJT base.

1.4 Current sensing monitoring networks

Accurately measuring the current drawn by loads connected to a board is essential for controlling the same loads and detecting abnormal conditions. For example, excessive current drawn may indicate the presence of an obstacle or a motor malfunction.

The AEK-MOT-8DCMH98 and AEK-MOT-4DCMH94 boards can measure the current drawn by the loads (for example, DC motors) connected to it using two methods: the standard method and an innovative indirect current measurement method.

The standard method directly measures the load current by using a properly dimensioned external sensing network. In this network, the shunt resistor is connected in series between the power supply of the load and the load itself, allowing the measurement of the voltage-drop across it and thus the current estimation.

The innovative indirect current measurement method uses external MOSFETs and does not require an external sensing network. This approach estimates the current without the classic shunt resistor in series with the load, thereby reducing system complexity and bill of materials (BOM) costs.

1.4.1 Standard current sensing based on external sense resistor connected in series

This method is based on current measurements through a sensing resistor connected in series between the power source of the load and the load itself.

Putting a resistor (R_{SHUNT}) in series with the load, the voltage across the resistor can be measured through the following formula:

$$V_{\mathrm{SHUNT}} = I \cdot R_{\mathrm{SHUNT}}$$

From V_{SHUNT} , you can calculate the current:

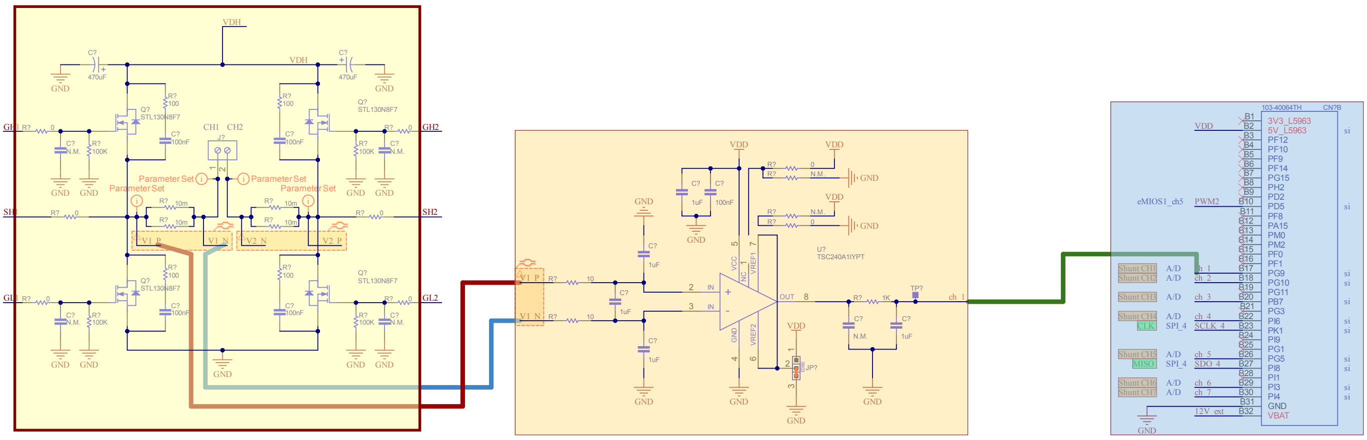
$$I_{LOAD} = \frac{V_{SHUNT}}{R_{SHUNT}}$$

Then, a TSC240 operational amplifier is used to amplify the voltage across the shunt by a fixed factor (gain). For example, for channel 1, the voltage is the result of the following calculation

$$V_{ch\_1} = V_{Shunt} \; * \mathrm{Gain}$$

The following figure shows the diagram of the current sensing network implemented, based on the TSC240 current sense amplifier.

Figure 6. Traditional current sensing network



1.4.1.1 How the standard current sensing has been implemented on the AEK-MOT-8DCMH98

Important: All the implementation data and measurements related to the AEK-MOT-8DCM98 also apply to the AEK-MOT-4DCMH94.

The current sensing network implemented on the AEK-MOT-8DCM98 manages up to 30 A per channel in H-bridge configuration and 15 A per channel in half-bridge configuration.

The current sensing network consists of:

- A shunt (sense) resistor R_{sense} in series with the load
- An op amp that amplifies the voltage across R_{sense}
- A microcontroller ADC that reads the amplified voltage

To get an accurate acquisition from the current sensing, we should set the minimum value of the current that we can acquire, choosing R_{sense} value so that the maximum current maps to near full-scale ADC voltage after its gain.

R_{sense} power rating must be safe at nominal and peak current.

Considering the op amp offset and the output saturation limits, we should define the minimum measurable current, calculating the sense voltage ($V_{\text{sns}} = I \cdot R_{\text{sense}}$) and the amplified output ($V_{\text{out}} = \text{Gain} \cdot V_{\text{sns}}$).

The procedure below describes how the current sensing network has been implemented on our board using shunt resistors in series.

Considering that:

- Nominal load current: $I_{\text{load}} = 30\text{A}$
- Maximum load current: $I_{\text{load(max)}} = 50\text{A}$ (i.e. peak current at power-up)
- ADC full-scale: $V_{\text{out(max)}} = 5\text{V}$ (voltage range that the ADC can read is 0 V - 5 V)
- Op amp: Gain = 20

We calculate the R_{SENSE} resistor. In the following formula, V_{OUT} is the maximum value that the ADC can read; GAIN is fixed at 50 and $I_{load(max)}$ is the maximum value of the current that the board can manage.

$$Rsense = \left(\frac{Vout}{Gain}\right)*\left(\frac{1}{Iload(max)}\right) = 0.005\ \Omega$$

We implemented 0.005 Ω using two resistors of 0.010 Ω, 5 W, in parallel.

Using the actual chosen value $R_{\text{sense}} = 0.005\Omega$, 10 W, at max. current (50 A), the power dissipation on the shunt is:

$$P_{\text{sns(max)}} = 0.005 \cdot 50^2 = 0.005 \cdot 2500 = 12.5\text{W}$$

Whereas, at nominal current (30 A), the power dissipation on the shunt is:

$$P_{\text{sns(nom)}} = Rsense*(Iload)^2 = 0.005 \cdot 30^2 = 0.005 \cdot 900 = 4.5\text{W}$$

The available power rating is 10 W, as we have two 0.010, 5 W resistors in parallel

So:

At 30 A, $P = 4.5\text{W} < 10\text{W}$ that is equal to the available power rating

At 50 A, $P = 12.5\text{W} > 10\text{W}$, which is not safe continuously but may be acceptable as a short-duration peak.

The sense voltage is calculated through the formula below:

$$V_{\text{sns}} = R_{\text{sense}} \cdot I_{\text{sns}}$$

With $I_{\text{sns}} = 30\text{A}$ and $R_{\text{sense}} = 0.005$, we obtain

$$V_{\text{sns}} = 0.005 \cdot 30 = 0.15\text{V}$$

The op amp output is equal to:

$$V_{\text{out}} = \text{Gain} \cdot V_{\text{sns}} = 20 \cdot 0.15 = 3\text{V}$$

So, at nominal current (30 A), the ADC sees about 3V.

Considering that the op amp input offset voltage is:

$$V_{\mathrm{offsetOpAmp}} = 20\mu\mathrm{V}$$

And the output low saturation is:

$$V_{\mathrm{OL}} = 10\mathrm{mV}$$

Small currents cannot be accurately measured, as the minimum measurable current ($Isns_{limit}$) that can be reliably read by the ADC is 0.104 A, calculated as follows:

$$Isns_{limit} = \frac{\left(\frac{Vol}{Gain}\right) + VoffsetOpAmp}{Rsns} = 0.104A$$

So, currents below about 0.104 A are not reliably distinguishable, because the op amp is near its lower limit and offset dominates.

The output voltage at the ADC for that minimum current ($Isns_{limit}$)is calculated as follows:

$$Vout = (Isns_{limit}{*}Rsns{*}Gain) - VoffsetOpAmp = 0.208\mu\mathrm{V}$$

So, the ADC sees about 0.208 µV as the minimum measurable current.

Considering the nominal current $I_{\mathrm{sns}} = 30\mathrm{A}$ and using the same formula:

$$Vout = (Isn{*}Rsns{*}Gain) - VoffsetOpAmp = 3V$$

We get 3 V at nominal current, taking offset into account.

Note: For further details, refer to the TSC240 documentation on www.st.com.

1.4.2 Indirect current measurement based on MOSFETs external to L99MH98

This method uses the MOSFET itself as the current sense element, instead of an external shunt resistor.

Briefly, instead of measuring current with a shunt resistor, the L99MH98 uses the external MOSFET -on resistance ($\boldsymbol{R}_{\mathrm{DS(on)}}$) as the “shunt” and measures the $\boldsymbol{V}_{\mathrm{DS(on)}}$:

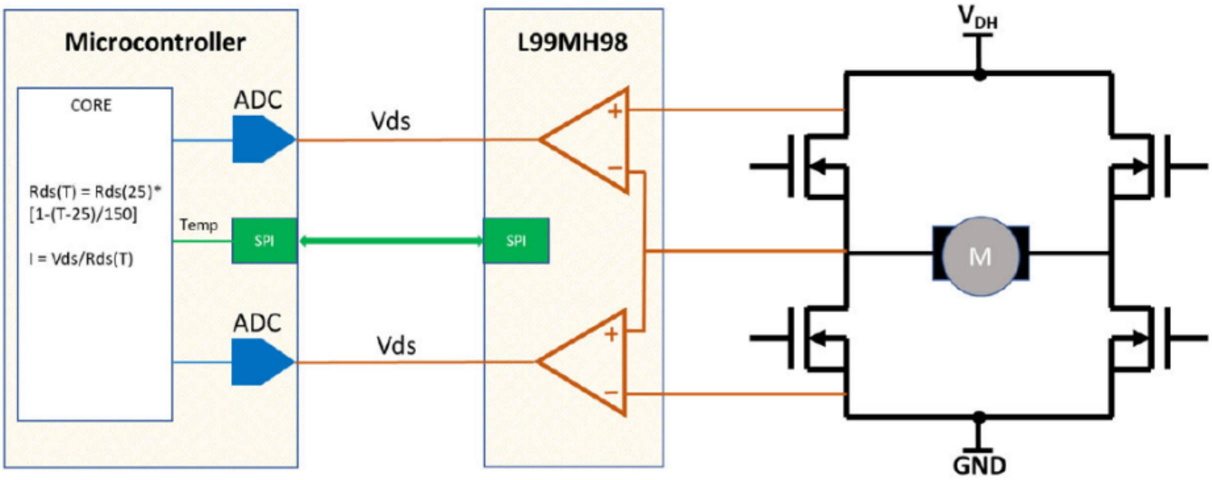
$$\boldsymbol{V}_{\mathrm{DS(on)}} = \boldsymbol{I} \cdot \boldsymbol{R}_{\mathrm{DS(on)}}$$

Then, the microcontroller computes current as

$$I \approx \frac{V_{\mathrm{DS(on)}}}{R_{\mathrm{DS(on)}}(T)}$$

where $\boldsymbol{R}_{\mathrm{DS(on)}}(\boldsymbol{T})$ is the MOSFET’s on resistance as a function of -temperature.

Figure 7. Overview of indirect current measurement



Thus, this method offers several benefits, such as lower BOM cost, as there is no external resistor sensing network, higher efficiency, and less wasted power, as there is no voltage drop across a shunt.

A key point in using the internal current sensing feature of the L99MH98 is the selection of the $\boldsymbol{R}_{\mathrm{DS(on)}}$ value of the external MOSFETs.

Some constraints must be considered regarding the V_{DS} voltage that the device can monitor and amplify with enough accuracy, without saturating the current-sense output (CSO) pins.

In fact, as $\boldsymbol{R}_{\mathrm{DS(on)}}$ increases, $\boldsymbol{V}_{\mathrm{DS(on)}}$ increases, improving current resolution. However, the losses in the MOSFET increase too (according to the formula $P_{loss} = I^2 \times \boldsymbol{R}_{\mathrm{DS(on)}}$).

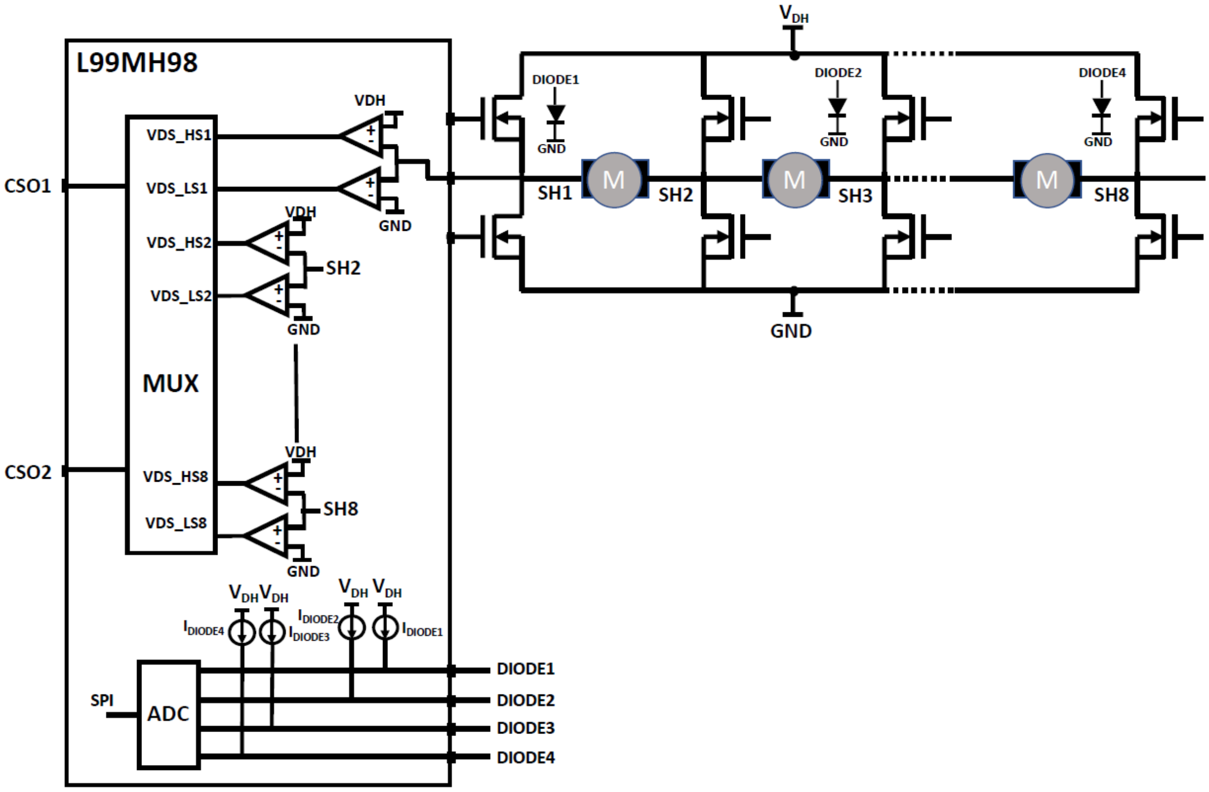
Therefore, a compromise is required between:

- MOSFETs with very low $\boldsymbol{R}_{\mathrm{DS(on)}}$ (for example, 1–2 mΩ), where $\boldsymbol{V}_{\mathrm{DS(on)}}$ is very small (a few millivolts at 10-20 A) and the L99MH98 must use a very high gain, which increases sensitivity to offset and noise, making current measurement less precise and robust
- And MOSFETs with higher $\boldsymbol{R}_{\mathrm{DS(on)}}$ (for example, 4–10 mΩ), where $\boldsymbol{V}_{\mathrm{DS(on)}}$ is larger (20–100 millivolts in the 5–20 A range) and allows using a moderate gain with a reliable CSO signal but increasing power losses in the MOSFET.

L99MH98 can measure V_{DS} of each of the 16 external MOSFETs (high and low- side-) and output an amplified version on CSO1 or CSO2 using internal amplifiers and an analog multiplexer.

The following figure shows the L99MH98 internal current sensing network, consisting of CSO pins, multiplexer and operational amplifiers, connected to external MOSFETs.

Figure 8. **Detailed network overview of L99MH98 internal current sensing**



The device amplifies V_{DS} using an internal gain with two stages: VDS_CONFx and CSO_GAIN_SELx. It then sends the amplified signal to the CSO1 or CSO2 pin, which can be read by the MCU analog-to-digital converter (ADC).

For accurate sensing, the MOSFET V_{DS} must meet the following conditions:

- The voltage must be high enough to stand out against offset and noise; typically, at least several tens of millivolts.
- The voltage must not be too high to avoid exceeding the dissipation limits of the MOSFET.

Via SPI configuration, you select which MOSFET V_{DS} is routed to CSO1 or CSO2 using the CSOSIGx and CSOSHx registers.

You enable/disable each CSOx output with the CSOENx bits (disabled → high-impedance).

The selected MOSFET V_{DS} is driven to CSOx only when that MOSFET is fully on.

After some dead time when the MOSFET turns on, CSOx is enabled.

A small capacitor on CSOx holds the voltage for stable ADC conversion by the microcontroller.

The first stage gain (per MOSFET, set via VDS_CONFx) is:

- 10 V/V if V_{DS} monitoring threshold is equal to 75 mV or 150 mV,
- 2.5 V/V if threshold is equal to 200 mV to 400 mV.

The second stage gain (per CSO channel, set via CSO_GAIN_SELx) is:

- 1.5 V/V when CSO_GAIN_SEL = 0.
- 3 V/V when CSO_GAIN_SEL = 1.

Considering that $\mathrm{Gtot} = \boldsymbol{G}_{\mathrm{stage1}} \times \boldsymbol{G}_{\mathrm{stage2}}$ and $V_{CSO} = V_{DS} \cdot G_{\mathrm{tot}}$, you must choose gains so that the CSOx output voltage (for your expected V_{DS}) falls in the valid range (from 0.1 V to -0.3 V as per related datasheet) ideally around the middle of this range for best ADC accuracy.

To improve indirect current measurement, L99MH98 can read temperature from up to 4 external diodes placed near each H-bridge (see Figure 8).

It drives each diode with a programmable current, measures its forward voltage V_f, which changes with temperature, reads it via ADC, and provides the result via SPI every $1\mathrm{ms}$.

The MCU converts V_f to temperature using a known temperature coefficient and a calibrated V_f at $25^{\circ}\mathrm{C}$ (ambient temperature, measured and stored during production).

Using the H-bridge- temperature (from external diodes) and the MOSFET V_{DS} (from CSO), the MCU knows $R_{\mathrm{DS(on)}}$ at the actual temperature and uses the stored $R_{\mathrm{DS(on)}}$ vs. temperature curve.

For the measured temperature, it interpolates $R_{\mathrm{DS(on)}}(T_{\mathrm{work}})$, where T_{work} is the ambient temperature, and computes the H-bridge current:

$$I_{\text{H-bridge}} \approx \frac{V_{DS}}{R_{\mathrm{DS(on)}}(T_{\mathrm{work}})}$$

Thus, current is obtained from temperature, avoiding the usage of a shunt resistor.

1.4.2.1 *Indirect current measurement implemented on the AEK-MOT-8DCMH98*

This section describes the indirect current measurement implementation on the AEK-MOT-8DCMH98.

Instead of putting a shunt resistor in series with the load, this method measures the MOSFET conduction voltage V_{DS} and, from that, indirectly calculates the load current:

$$I_{\mathrm{LOAD}} = \frac{V_{DS}}{R_{DS\_ON}}$$

So, this method measures V_{DS} accurately (through an internal amplifier and ADC) and estimates the instantaneous R_{DS_ON} at the real MOSFET temperature.

The L99MH98 has an internal multiplexer (MUX) and amplifier chain to convert a small V_{DS} into a measurable voltage at the CSO pin.

The first stage gain ($Gain_1$) is set by VDS_CONFIG register:

- If VDS_CONFIG = 0000 (75 mV) or 0001 (150 mV): $\mathrm{Gain}_1 = 10$
- If VDS_CONFIG = 0010 (0.2 V) or any value from 1xxx (>2): $\mathrm{Gain}_1 = 2.5$

Small V_{DS} use high gain (10), while larger V_{DS} use lower gain (2.5).

So, the output remains within a usable ADC range and avoids saturation.

The second amplification stage adjusts the signal so that the CSO pin is centered around $\frac{V_{DD}}{2}$ (in this case, we chose 3).

The total gain is:

$$Gtot = Gain_1 {*} Gain_2 = 30$$

Therefore, the V_{CSO} is:

$$VCSO = VDS {*} Gtot = \ I_{Load} {*} R_{DS_{ON}} {*} Gtot$$

$R_{DS_{ON}}$ is not constant: it changes strongly with temperature. At 25°C, $R_{DS_{ON}}$ equals the $R_{DS_{ON}}$ measured during calibration. At temperature T = X, $R_{DS_{ON}}$ is calculated using the following formula:

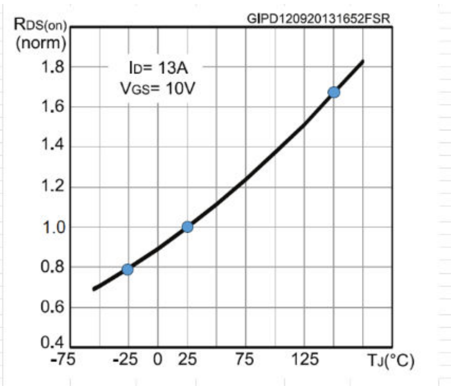
$$R_{DS_{(\mathrm{ON})}} = a {*} T^2 + b {*} T + c$$

The values of a, b, and c are the actual, non-normalized coefficients of the second-order parabola equation, calculated as follows:

- Given three points taken from the graph of $R_{DS_{ON}}$ (MOSFET of the H-bridge) according to the temperature, we obtain $R_{DS_{ON}}$ normalized values (relative to R_{DS_ON} at $25^{\circ}C$) , as shown in the table below.

Table 1. RDSON normalized values at different temperatures

Graph points	Tj(°C)	$R_{DS_{ON}}$ norm
P1	-25	0.79
P2	25	1
P3	150	1.68



- Using the Cramer's method, the normalized values are obtained:
  - a = 0.00000709
  - b = 0.0042
  - c = 0.89057143
- Multiplying these values by $R_{DS_{ON}}@25°C$ (during the calibration phase), we obtain the actual values:
  - $a = 0.00004049$
  - $b = 0.02400000$
  - $c = 5.088979592$

The MOSFET junction temperature is not directly measured. Instead, it is calculated by measuring the temperature of a nearby diode used as a sensor and estimating the MOSFET junction temperature from the diode temperature using thermal resistances.

A PN diode forward voltage (V_{AK}) decreases with temperature.

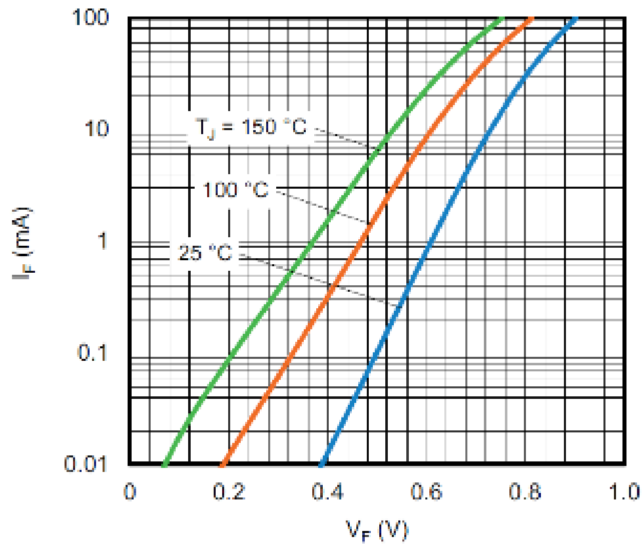
The value of T (MOS temperature) is obtained through the following steps:

1. Set the current flowing through the diodes by programming the relevant registers (see L99MH98 datasheet). In this case:

$$I_{diode} = 1\text{mA}$$

2. Bias the PN junction: the value of $V_{AK} = V_F$ (for the diode selected, P/N = 1N4148W-HE3_A-08) at different temperatures is shown below:

Figure 9. V_{AK} = V_F value at different temperatures



This means that the slope, which is the variation of V_{AK} based on temperature, is equal to α = -2.2 mV/°C and V_{AK} decreases by about 2.2 mV for each 1°C increase.

The ADC of L99MH98 measures the diode voltage.

The value of α is required to calculate the $V_{AK}$of the diode using the following formula:

$$V_{AK}diode\left(@T°C\right) = \frac{\left\{\left[DIODEx_{Readx_{10}}*\left(\frac{2.2}{2048}\right)\right]*\alpha\right\}}{n}$$

Where:

- $DIODEx_{Readx_{10}}$ = ADC register value in base 10
- $Vref_{ADC} = 2.2$ V
- Bit_ADC = 11 (corresponding to 2048 quantization levels or V_ADC levels)
- α = -2.2 mV/°C
- n = number of diodes

The difference between $V_{AK}@25°C$ (measured during the calibration phase) and $V_{AK}@Tx$ (measured at the operating temperature x), divided by the value of α, provides the temperature increase. This value indicates how much the temperature of the diodes has increased:

$$(V_{AK}@25°C - V_{AK}@Tx)/\alpha = Tx$$

The value of T_x plus T_{amb} (in this case, the calibration temperature of the laboratory in °C) must be added to ∆T, which is the temperature difference (measured with a thermal camera) between the top of the diode and the top of the MOSFET.

The diode is not exactly at the same temperature as the MOSFET silicon. There is a thermal gradient between them.

The temperature at the top of the MOSFET is necessary to calculate, using $R_{TH}MOS$ (that is the MOSFET thermal resistance, the actual temperature of the silicon inside the MOSFET package. By adding $(R_{TH}MOS*P_D)$, where P_D is the power dissipated by the MOSFET during the acquisition, we obtain the junction temperature of the MOSFET:

$$T_JMOS = Tx_{DIODE} + T_{amb} + (R_{TH}MOS*P_D)$$

Once $T_{J,\mathrm{MOS}}$ is known, you can determine $R_{DS_{ON}}$ at that specific moment:

$$R_{DS\_ON}\left(T_{J,\mathrm{MOS}}\right) = aT_{J,\mathrm{MOS}}^2 + bT_{J,\mathrm{MOS}} + c$$

Consequently, we can determine the current ($I_{LOAD} = I_{DMOS}$) flowing through it as follows:

$$I_{LOAD} = \frac{V_{DS(measuredthroughCSOx)}}{R_{DS_{ON}}} \text{ (A)}$$

1.4.2.2 *Indirect current measurement software implementation on the AEK-MOT-8DCMH98*

According to the method described in the previous section, a set of software functions has been developed to implement the indirect current measurement feature of the L99MH98 and the L99MH94.

These software functions are available in AutoDevKit Studio in the dedicated demos (see Section 2.2.3 for further details).

The indirect current measurement method strongly depends on the electrical characteristics of the power devices mounted on the application board and on the external MOSFETs, including their nominal $R_{DS(on)}$ value and thermal behavior. Thus, the measurement results and the demo are strictly related to the AEK-MOT-8DCMH98/ AEK-MOT-4DCMH94 boards and the onboard L99MH98/L99MH94.

Porting this software to a different board design or to different MOSFETs requires a new characterization and recalibration phase.

1.4.2.2.1 Calibration procedure

A preliminary calibration procedure is required before performing the indirect current measurement.

The purpose of this procedure is to determine the $R_{DS(on)}$ value at 25°C, which is later used as the reference value in the software calculation.

The hardware setup to perform this calibration is shown below.

Figure 10. Hardware setup for the calibration procedure for AEK-MOT-8DCMH98

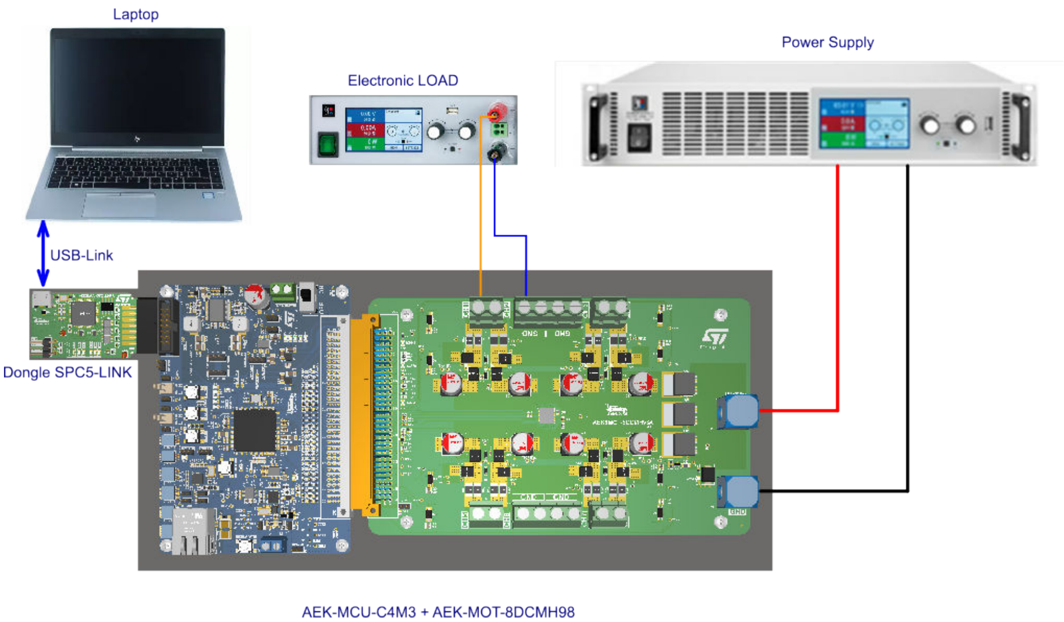
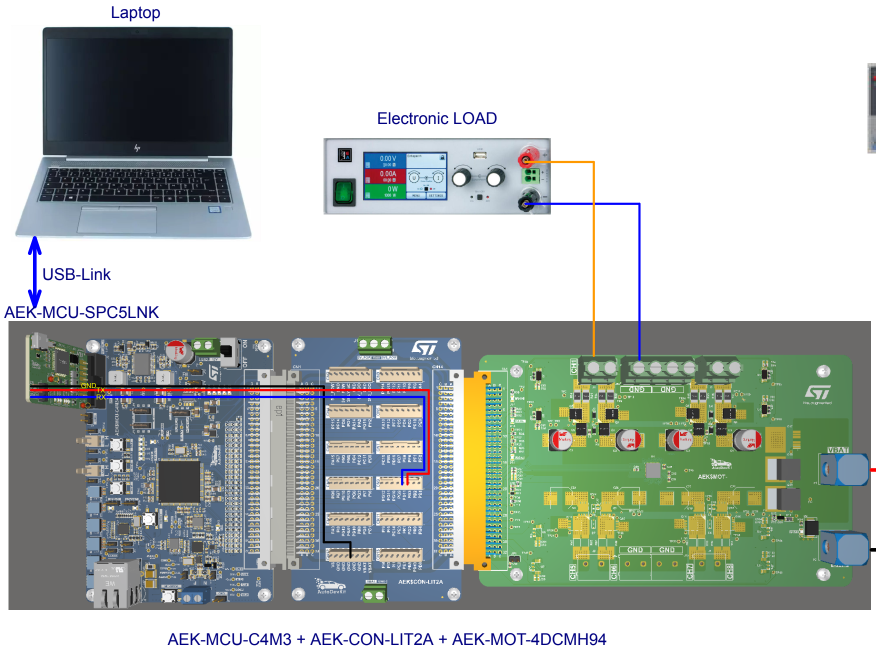


Figure 11. Hardware setup for the calibration procedure for AEK-MOT-4DCMH94



The calibration was performed by:

1. enabling one channel,
2. forcing a known current through the selected MOSFET,
3. measuring the corresponding V_{DS} through one of the available CSO pins
4. keeping the channel enabled only for a very short time.

This last condition is essential as the MOSFET must remain on only briefly, to avoid self-heating and to obtain an $R_{DS(on)}$ value as close as possible to the actual value at 25°C.

In our implementation, the calibration of $R_{DS(on)}$ at 25°C was carried out by configuring a full bridge on channels 1 and 2, and by measuring the high-side MOSFET of channel 1.

Starting from $R_{DS} = \frac{V_{DS}}{I_{DS}}$, the calibrated $R_{DS(on)}$ at 25°C can be obtained, where:

- V_{DS} is derived from the voltage measured on CSO1, divided by the product of the two gain stages:
  - stage 1 gain = 10V/V, since VDS_CONF = 150 mV
  - stage 2 gain = 3V/V, configured through the dedicated register
  - Therefore, the total gain is: $G_{tot} = 10 \times 3 = 30\text{V/V}$
- I_{DS} is the known forced current.

In this implementation, the reference $R_{DS(on)}$ value at 25°C was characterized on the high-side MOSFET of channel 1.

The final calibration value was computed as the arithmetic mean of three different measurements, carried out at 5 A, 10 A, and 20 A.

For each current level, the resistance was calculated from the measured V_{DS} according to the following formula:

$$R_{DS(on),cal} = \frac{R_{DS,5A} + R_{DS,10A} + R_{DS,20A}}{3}$$

This method provides a more robust reference value and mitigates the effect of possible deviations in a single measurement point.

The average measured value led to the following calibrated resistance:

$$R_{DS(on),cal} = 0.003508250\Omega$$

This value has been stored in the demo as a C #define and is used by the indirect current measurement functions described in the following section.

1.4.2.2.2 Software implementation #define functions

The software implementation relies on a set of #define constants derived from calibration activities, board characterization, and MOSFET thermal modeling.

These constants are specific to the considered hardware setup and must be re-evaluated whenever different MOSFETs, board layouts, or thermal sensing placements are used.

The table below lists the currently used values and related meaning.

Table 2. List of #define functions

#define	Value	Meaning
L99MH9x_CH_MOSFET_RDS	0.00350825 Ω	Calibrated MOSFET $R_{DS(on)}$reference value at 25°C, used as the starting point for the temperature-dependent resistance model
L99MH9x_RDS_ON_COEFFICIENT_A	0.00000709	Coefficients of the polynomial model used to estimate $R_{DS(on)}$ as a function of the MOSFET temperature
L99MH9x_RDS_ON_COEFFICIENT_B	0.0042	
L99MH9x_RDS_ON_COEFFICIENT_C	0.89057143	
L99MH9x_RDS_DELTA_T_DIODE_MOS	3.98°	Experimentally derived correction factor used to estimate the temperature difference between the diode sensing point and the actual MOSFET junction
L99MH9x_DIODE_VF_25C_MV	615 mV	Forward voltage of the temperature sensing diode at the reference temperature of 25°C
L99MH9x_DIODE_TEMP_COEFF_MV_PER_C	(-2.2f) mV/°C	Diode temperature coefficient used to convert the diode forward voltage variation into temperature variation
L99MH9x_DIODE_REF_TEMP_C	25.0°C	Reference temperature used for the diode model, equal to 25°C

1.4.2.2.3 Current measurement function

The main function developed to perform the indirect measurement of the current flowing through a given half-bridge side at a given time is:

```
float
L99MH9x_ch_measureHBSideCurrentIndirectlyOnCSO1(
L99MH9x_dev_name_t L99MH98_dev_name,
    L99MH9x_ch_name_t L99MH98_ch_name,
    L99MH9x_hbSide_t L99MH98_hbSide
  );
```

This function performs the indirect current measurement on the selected low-side or high-side MOSFET of a given half-bridge, using CSO1, using:

- the L99MH9x identifier
- the channel identifier
- the low-side or high-side half-bridge identifier

The function returns the indirectly measured current value, computed through the following formula:

$$I_{DS} = \frac{V_{DS}}{R_{DS(on)}(T)}$$

Where:

- V_{DS} is the instantaneous drain-to-source voltage measured through CSO1
- $R_{DS(on)}(T)$ is the MOSFET on-resistance estimated at the current junction temperature.

This function relies on two other functions:

1. a function to measure V_{DS}
2. a function to estimate $R_{DS(on)}$ as a function of temperature

These two functions are detailed in the next two sub-sections.

1.4.2.2.3.1 Measurement of V_{DS} through CSO1

To calculate the drain-to-source voltage of the selected channel and side through CSO1, we used the following function:

```
float L99MH98_ch_measureHBSideVdsOnCSO1(
L99MH9x_dev_name_t L99MH98_dev_name,
    L99MH9x_ch_name_t L99MH98_ch_name,
    L99MH9x_hbSide_t L99MH98_hbSide
  );
```

Which:

1. validates the input arguments
2. reads the VDS_CONF of the selected channel
3. determines the first gain stage according to the configured V_{DS} monitoring threshold:
   - 10 V or thresholds below 200 mW
   - 2.5 otherwise
4. forces the second gain stage to 3 V by setting the corresponding CSO gain register
5. enables CSO1
6. maps the selected channel and half-bridge side (HS or LS) onto CSO1
7. triggers an ADC measurement on CSO1
8. converts the measured CSO voltage back to the actual MOSFET V_{DS} by dividing by the total gain

Therefore, if the measured CSO voltage is indicated as V_{CSO} , the actual drain-to-source voltage is computed through the following formula:

$$V_{DS} = \frac{V_{CSO}}{G_1 \cdot G_2}$$

Where:

- G_1 is the first gain stage, either 10 or 2.5
- G_2 = 3

1.4.2.2.3.2 Estimation of $R_{DS(on)}$ as a function of temperature

To estimate the MOSFET on-resistance based on the current temperature, we used the following function:

```
float L99MH9x_ch_getRds(
L99MH9x_dev_name_t L99MH98_dev_name,
L99MH9x_ch_name_t L99MH98_ch_name
);
```

This function estimates the instantaneous $R_{DS(on)}$ value of the MOSFET by exploiting the external temperature diodes available on the board.

Each diode is associated with a pair of channels, as follows:

- channels 1–2 → DIODE1
- channels 3–4 → DIODE2
- channels 5–6 → DIODE3
- channels 7–8 → DIODE4

Based on the selected channel, the software determines which diode measurement must be used.

The diode ADC reading is then converted into a forward voltage value expressed in millivolts.

Starting from this value, the diode temperature is estimated by comparing the measured forward voltage with the reference forward voltage at 25°C, through the following formulas:

$$\Delta V = V_F(T) - V_F(25^{\circ}\mathrm{C})$$

$$\Delta T = \frac{\Delta V}{K_T}$$

Where:

- $V_F(25^{\circ}\text{C}) = 615mV$ is the experimentally derived diode forward voltage at the reference temperature
- $K_T = -2.2\text{mV}/^{\circ}\text{C}$ is the diode temperature coefficient

The diode temperature is then given by:

$$T_{diode} = 25^{\circ}\text{C} + \Delta T$$

Since the diode is not physically placed exactly on the MOSFET junction, an experimentally derived correction factor is applied to estimate the MOSFET temperature:

$$T_{MOSFET} = T_{diode} + \Delta T_{corr} = T_{diode} + 3.98^{\circ}\text{C}$$

Finally, the MOSFET on-resistance is computed starting from the calibrated $R_{DS(on)}$ value at 25°C and applying the equation below, obtaining the instantaneous $R_{DS(on)}$ value used by the software current measurement routine:

$$R_{DS(on)}\left(T\right) = R_{DS(on),25^{\circ}\text{C}} \cdot \left(A \cdot T^2 + B \cdot T + C\right)$$

Where:

- *A*, *B*, and *C* are the polynomial coefficients defined for the selected MOSFET
- *T* is the estimated MOSFET temperature

The current final computation is then obtained considering the instantaneous V_{DS} and the estimated $R_{DS(on)}(T)$, using the following formula, $I_{DS} = \dfrac{V_{DS}}{R_{DS(on)}\left(T\right)}$, through the L99MH9x_ch_measureHBSideCurrentIndirectlyOnCSO1() function.

1.5 Protections and diagnostics

The following protections and diagnostic features have been implemented on the board:

- Watchdog timeout by MCU control board
- Drain-source monitoring for short-circuit detection
- Undervoltage lockout
- Reverse battery protection dedicated circuit
- Overtemperature warning and shutdown
- Detailed off-state diagnostic via SPI
- Programmable diagnostic load on all channels

1.5.1 ESD protections

ESD protection devices are present on the lines connected to the microcontroller unit (MCU) and on the V_{BAT} power supply.

On V_{BAT}, D9 (SM15T27CAY) bidirectional transient voltage suppressor (TVS) diode that clamps energy spikes at 27 V.

On the lines routing signals from the AEK-MOT-8DCMH98 to the MCU, 14 ESDLIN1524BJ TVS diodes are present. They are designed to protect local interconnect network (LIN) bus and clock extension peripheral interface (CXPI) against electrostatic discharge (ESD) and other transient surges, such as those defined in ISO 7637-3.

1.5.2 Watchdog

After powerup, the watchdog is on by default and starts running with a long open window. During this time, the microcontroller initializes the L99MH9x, and the watchdog disabling procedure can be run if the application requires no watchdog.

To start normal window mode, the microcontroller must write a specific bit to the watchdog trigger/disable register (WDGTRDIS) before the end of the long open window.

After the first valid watchdog trigger, the watchdog will enter window mode. In this mode, the microcontroller must keep the watchdog alive by writing bits of the watchdog trigger/disable register (WDGTRDIS). Any correct watchdog trigger SPI frame will immediately start a new window.

In case of a watchdog failure (trigger too early/late, wrong value, bad/incorrect disable key, timeout, etc.), the WDG_ERROR flag stops the watchdog and puts the device in fail-safe mode. The OUTEx control bits are reset, and the gate drivers are forced to switch off all the MOSFETs with the maximum discharge current.

To recover from failsafe mode, the WDG_ERROR flag must be cleared, and then the OUTEx control bits must be set to 1 via SPI.

To enter window mode again, the microcontroller must write the specific bit to the watchdog trigger/disable register (WDGTRDIS) again.

To enable or disable the watchdog, the microcontroller must write a specific key, consisting of two consecutive valid SPI frames to be sent in a determined order.

Any other SPI transfer between the two SPI frames carrying the key, including an invalid SPI transfer, stops the disabling process and generates a watchdog fault (WDG_ERROR).

Besides, the keys sent in the wrong order will not disable the watchdog and generate a watchdog fault as well.

1.5.3 Diagnostic not output (DIAGN)

The board also features a diagnostic negative active output (DIAGN), which is used to detect device faults, including device power-on-reset events. The purpose of the DIAGN output pin is to warn immediately the microcontroller that a new fault has been detected by the device, avoiding cyclic on-demand failure check via SPI. When a new fault occurs, the red LED (D14) will turn on. All errors will be mapped in the DIAGCR control register.

1.5.4 Diagnostic in off mode

By cycling through 3 pullup/pulldown setups and reading SH1/SH2 via the diagnostic bits, the external microcontroller can fully analyze wiring and load faults of a DC motor driven by two half-bridges, all while the MOSFETs remain off (no current through the motor).

Off state diagnostics are executed with MOSFETs off, so you can check rarely used loads and detect shorts before turning on, avoiding MOSFET stress.

With MOSFETs OFF, L99MH98 can detect:

- SHx short to VDH
- SHx short to GND
- Open load

The MCU enables/disables diagnostic currents, reads SHx logic levels (both 0 → SHx low, both 1 → SHx high) and combines SHx level with the applied pull-up/pull-down pattern detecting open load, short to GND, or short to VDH, and consequently blocking activation.

For a DC motor between HB1 and HB2 (SH1–motor–SH2), the MCU runs 3 current configurations:

- Cfg1: both SH1 and SH2 pulled down
- Cfg2: SH1 pulled up, SH2 pulled down
- Cfg3: SH1 pulled down, SH2 pulled up

By comparing SH1/SH2 levels in these 3 cases, the MCU can distinguish:

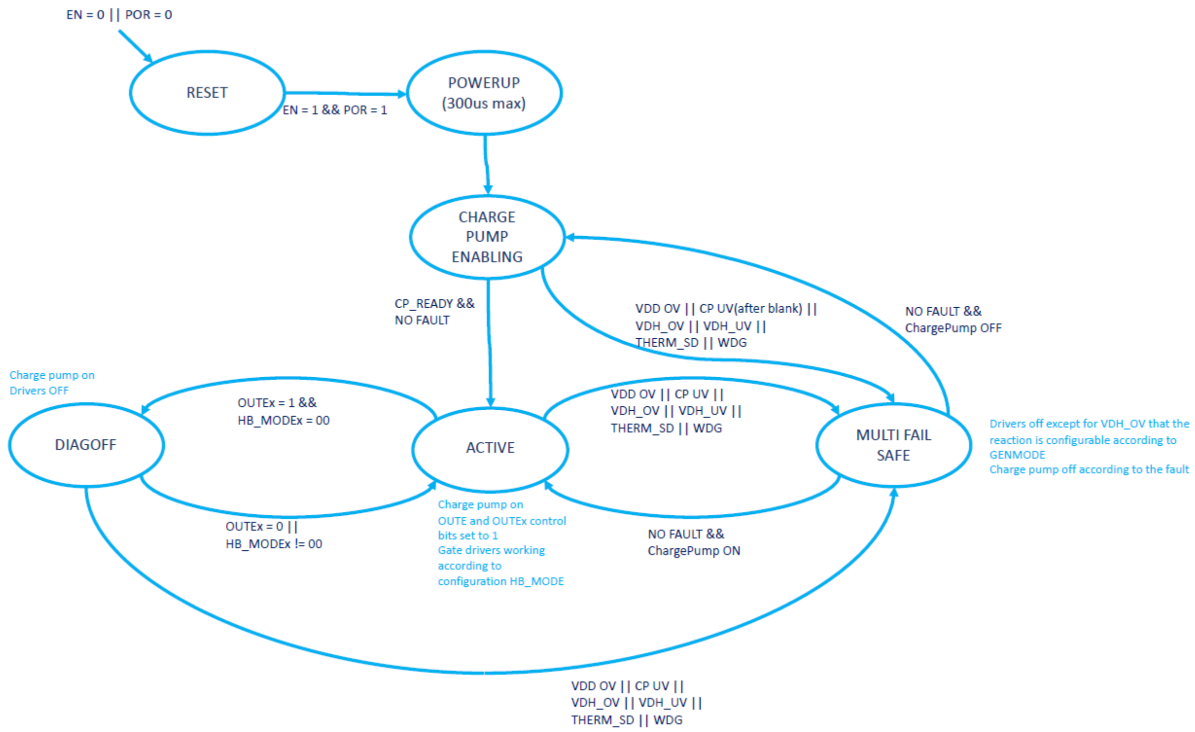
- Correct motor connection between SH1 and SH2
- Open load (motor missing / wiring open)
- Short on SH1 or SH2 to VDH or on GND.

1.6 L99MH98 state machine

The figure below shows the L99MH98 finite state machine (FSM).

Note: This finite state machine diagram shown below also applies to the L99MH94.

Figure 12. **L99MH98 finite state machine**



The main states are:

- **Reset**: the device exits reset mode and enters the power-up state when the EN pin is high, and V_{DD} rises above V_{DDPOR_OFF}. If V_{DD} drops below V_{DDPOR_ON} while the EN pin remains high, the device performs a power-on reset and enters reset mode. If the EN input pin is floating, the internal pull-down resistor causes the device to enter reset mode and minimize current consumption.
- **Power-up and charge pump enablement**: this is an intermediate state with the aim of loading all the configurations necessary for the device to function. When the charge pump is out of the power-up phase, the device will automatically exit from the charge pump enabling state to go to the active state.
- **Active**: if no fault occurs, the charge pump is enabled if $V_{DH} > V_{DHUV}$, the gate drivers are enabled if the OUTEx, x = 1...8, one for each half-bridge, control bits are set and the OUTE bit (one generic for all the gate drivers) is set. If the OUTEx control bits are reset, or the OUTE bit is reset, all the gate drivers are disabled and all the MOSFETs are switched off passively through the internal resistive connection between gate and source present at each MOSFET.
- **Multi fail-safe**: an automatic system intervenes to switch off passively the gate driver/s to protect the device/application if a fault happens according to the registers settings. When a fault condition is detected, the behavior of the device is different depending on the cause of the fault itself.
- **Diagoff**: the device disables diagnostic and protection functions (or part of them) for the outputs, to avoid false fault detections in special conditions (e.g., certain loads, test configurations, or start-up behaviors).

1.7 Channel configuration

The AEK-MOT-8DCMH98 board manages eight channels (CH1 to CH8), controlled by 16 power MOSFETs (STL130N8F7).

The AEK-MOT-4DCMH94 board, instead, manages 4 channels (CH1 to CH4), controlled by 8 power MOSFETs (STL130N8F7).

The onboard MOSFETs dissipate the heat generated during the energy transition phase, from cutoff to saturation.

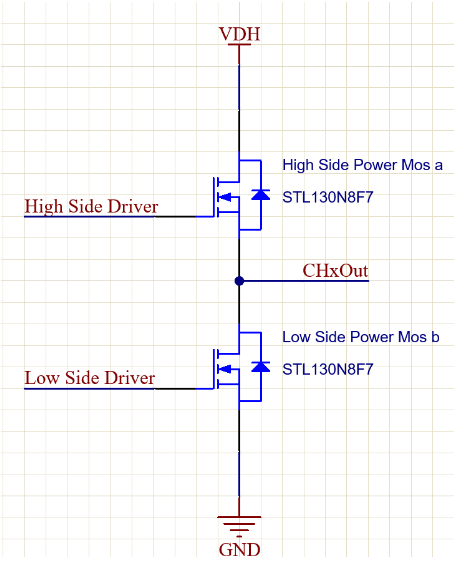
Each device is configured individually through the L99MH98/L99MH94 configuration registers via SPI bus (see the related datasheets).

Channels can be configured in half-bridge or full-bridge modes.

1.7.1 Half-bridge configuration

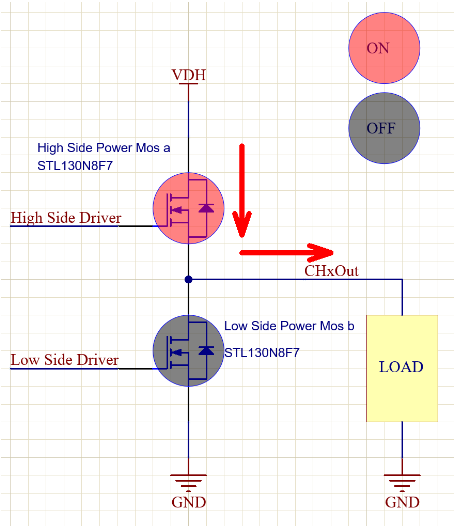
In the half-bridge configuration, each channel uses a couple of power MOSFETs. The power MOSFET with its drain connected to the positive power supply is the high-side (HS) device, and the power MOSFET with its source connected to ground is the low-side (LS) device. The two devices, HS and LS, form the half bridge (see the following figure).

Figure 13. Half bridge



It is possible to use the individual channels (from CH1 to CH8) for loads that draw current in only one direction (unidirectional mode), as shown in the following example:

Figure 14. Half-bridge current flow

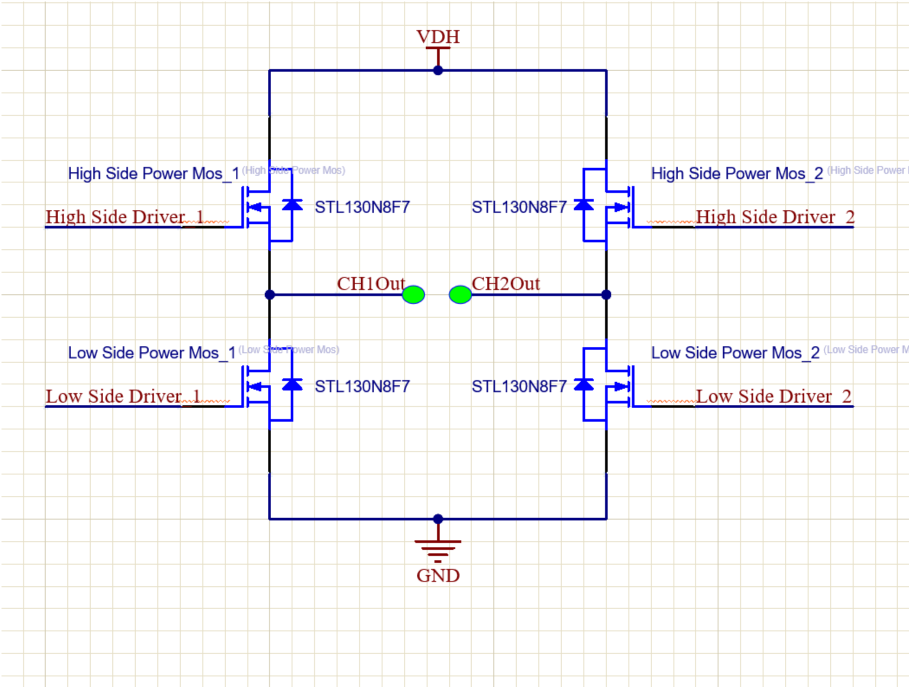


1.7.2 Full-bridge configuration

The full bridge consists of two pairs of power MOSFETs. The power MOSFETs with their drains connected to the positive power supply are the high-side devices (HS1 and HS2), and the power MOSFETs with their sources connected to ground are the low-side devices (LS1 and LS2).

The four devices HS1, HS2, LS1, and LS2 form the H-bridge (see the following figure).

Figure 15. Full bridge



This configuration is used when current must flow in both directions. This mode, called bidirectional mode, allows a motor to rotate in either direction (clockwise or counterclockwise). The figures below show the two directions of rotation, with the corresponding power MOSFETs activated or deactivated (ON or OFF).

Figure 16. Motor clockwise rotation

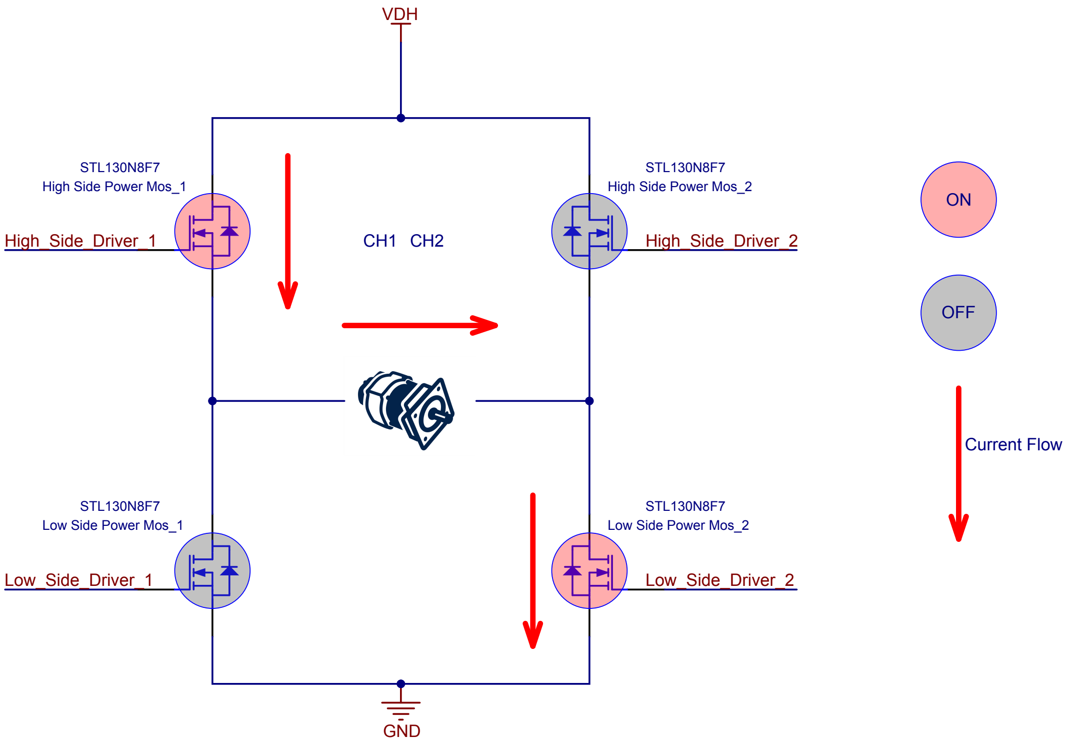
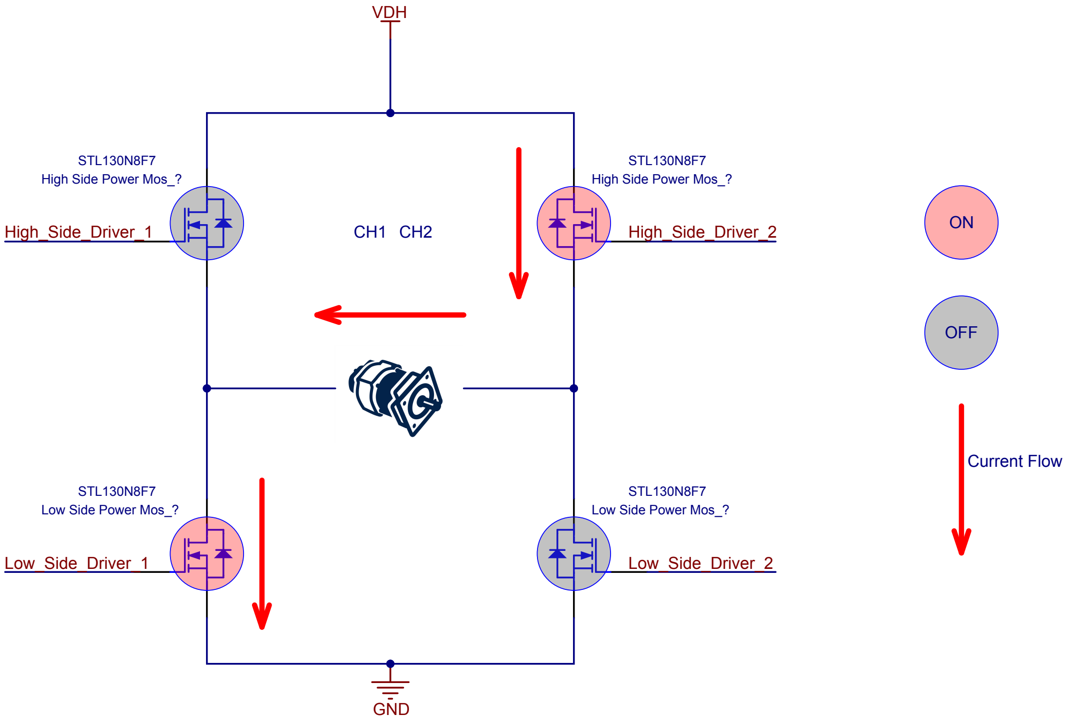


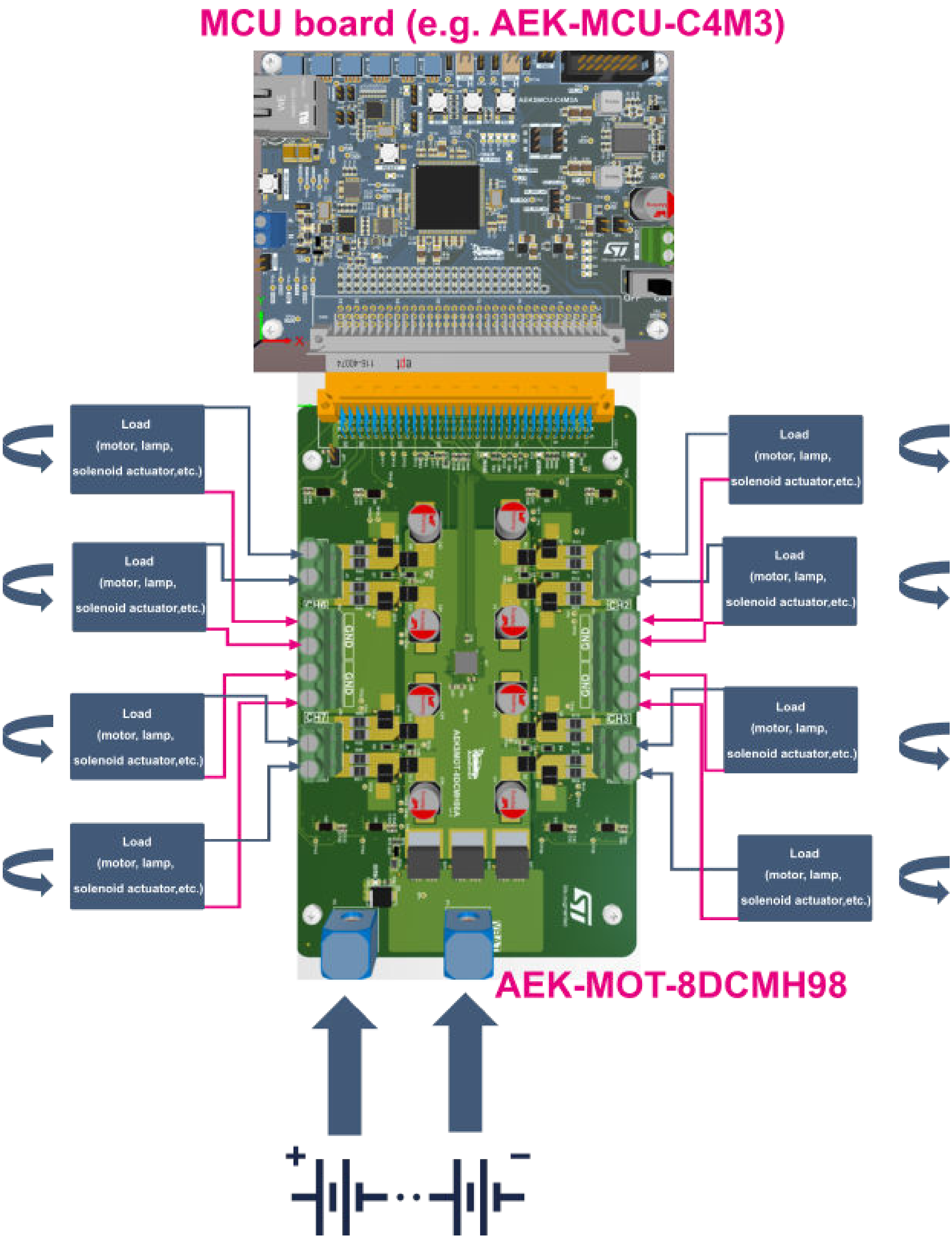
Figure 17. Motor counterclockwise rotation



Below are some examples of application diagrams.

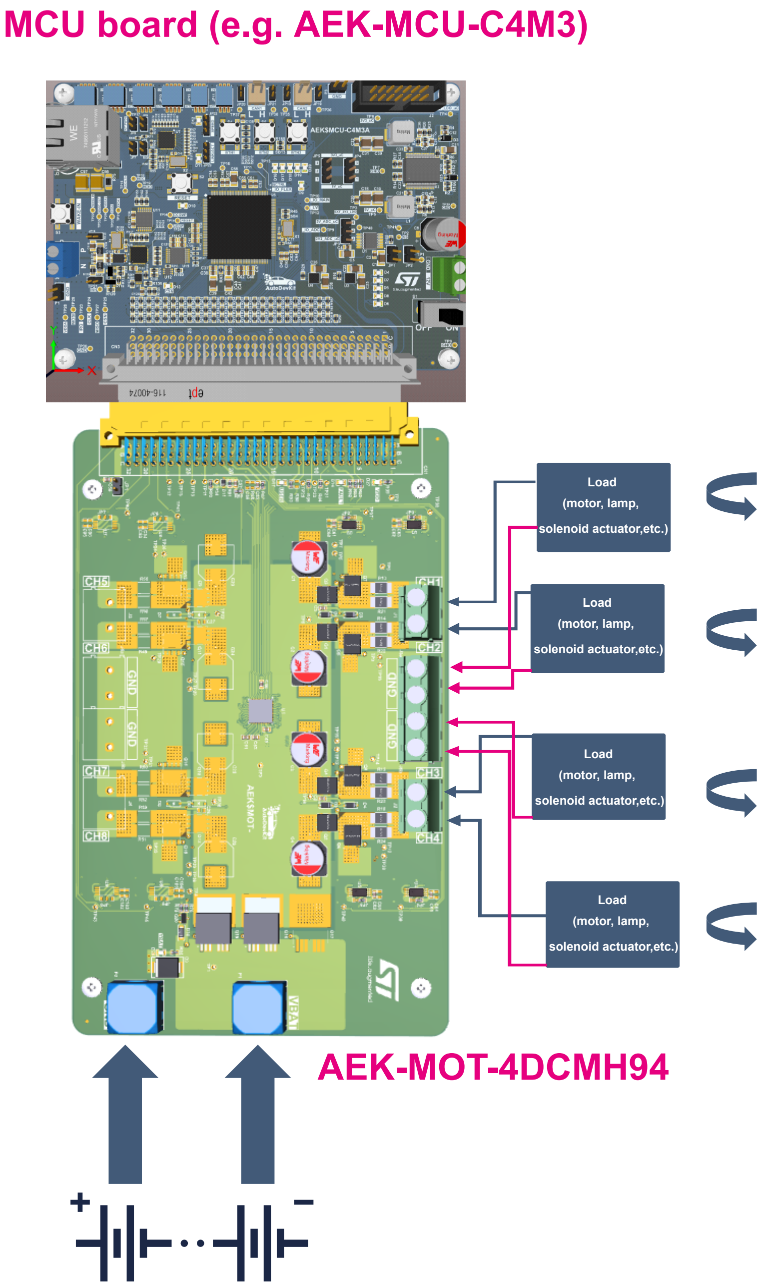
The following figure shows the connections between the AEK-MOT-8DCMH98 board and the AEK-MCU-C4M3 when using the eight channels in unidirectional mode (CH1, CH2, CH3, CH4, CH5, CH6, CH7, CH8).

Figure 18. **8-unidirectional DC motors application diagram**



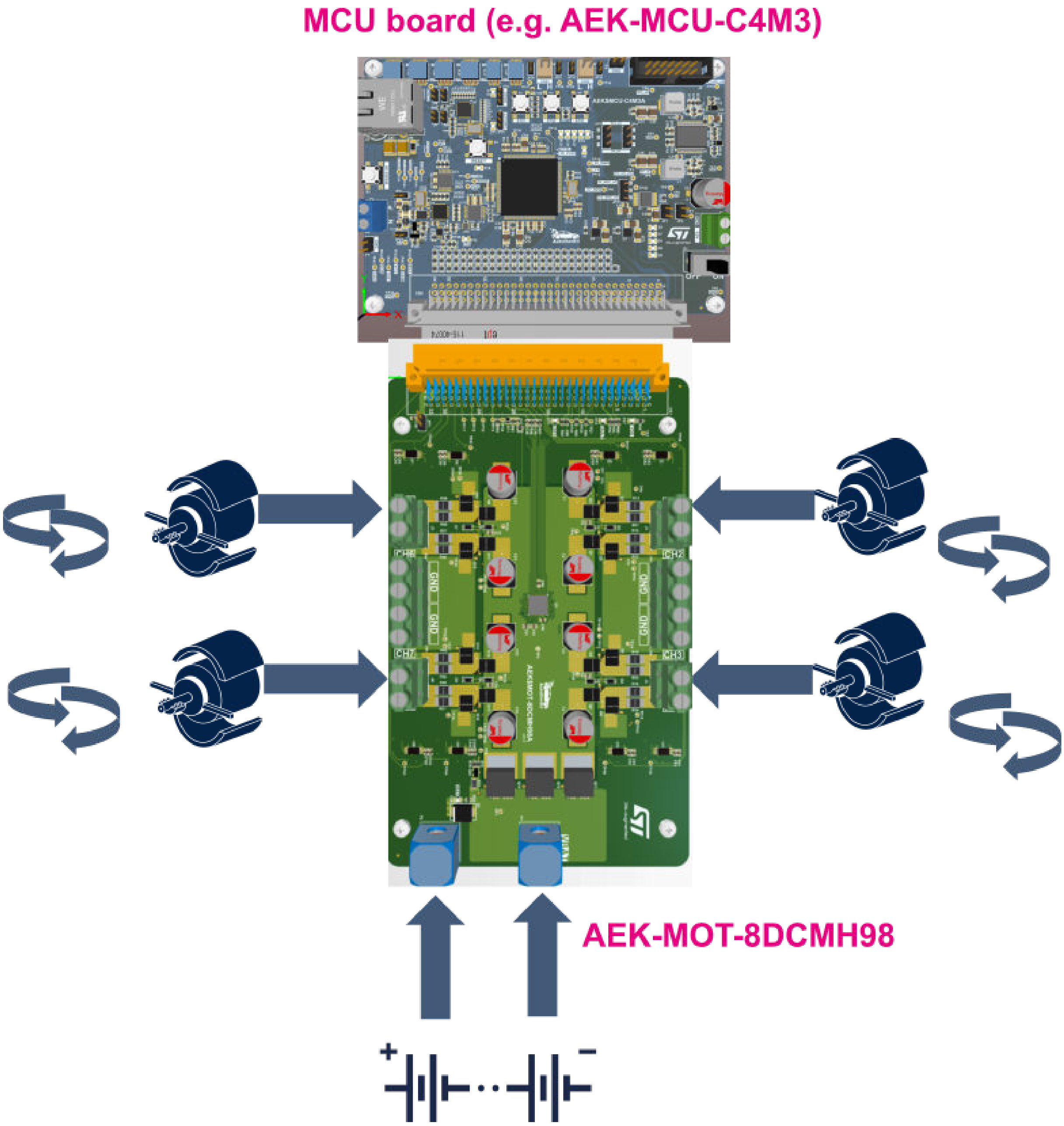
The following figure shows the connections between the AEK-MOT-4DCMH94 board and the AEK-MCU-C4M3 when using the 4 channels in unidirectional mode (CH1, CH2, CH3, CH4).

Figure 19. 4-unidirectional DC motors application diagram



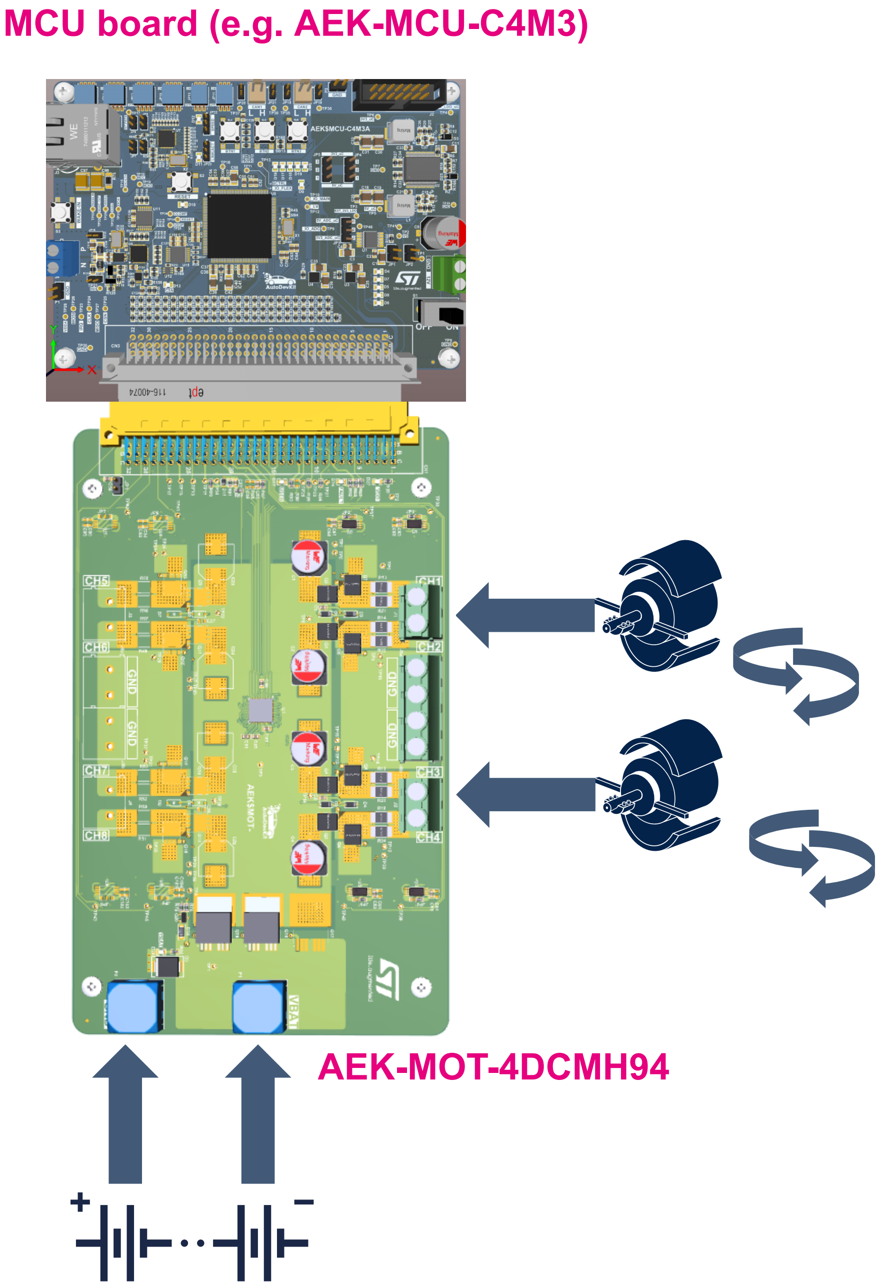
The following figure shows the connections between the AEK-MOT-8DCMH98 board and the AEK-MCU-C4M3 when using the eight channels in bidirectional mode, that is using couples of channels (CH1+CH2, CH3+CH4, CH5+CH6, CH7+CH8).

Figure 20. **4-bidirectional DC motors application diagram**



The following figure shows the connections between the AEK-MOT-4DCMH94 board and the AEK-MCU-C4M3 when using the 4 channels in bidirectional mode, that is using couples of channels (CH1+CH2, CH3+CH4).

Figure 21. 2-bidirectional DC motors application diagram



1.8 How to drive external MOSFETs through L99MH98/L99MH94: three-stage gate current

The L99MH98/L99MH94 split each switching event (power-on and power-off) into three V_{GS} zones. In each zone, you can set a different gate current (separately for on and off).

Stage 1 – Low V_{GS}: initial charging / discharging

This is the very beginning of the transition, when the gate is just starting to charge or discharge from 0 V. You might choose a higher current here to quickly reach the region where the MOSFET starts to conduct.

Stage 2 – Middle V_{GS}: Miller / switching region

This is typically where most switching losses are determined (often around the Miller plateau). You can slow down the transition (smaller current) to reduce EMI and ringing, or speed it up (larger current) if efficiency is more important.

Stage 3 – High V_{GS}: final region / fully ON or OFF

This is the end of the transition:

- For turn on: gate is driven up to its final full drive voltage.
- For turn off: gate is pulled down from a high level to 0.

You can again choose a higher current here to complete the transition quickly without strongly impacting EMI.

In summary, each MOSFET channel has its own set of thresholds and current values. Thus, you can use different gate current profiles for turn-on and turn-off as well as for each individual MOSFET (e.g., high-side vs low-side, different packages, different loads), reaching lower EMI and ringing (slower current in Stage 2), lower switching losses and better efficiency (faster in Stages 1 and 3), and fine-tuning the behavior per channel instead of "one size fits all" gate drive.

1.9 Testing the board

1.9.1 Test setup

The figures below show the complete setup required to perform current measurements on the AEK-MOT-8DCMH98 in a four H-bridge configuration and on the AEK-MOT-4DCMH94 in a two H-bridge configuration.

Figure 22. Test setup for the AEK-MOT-8DCMH98

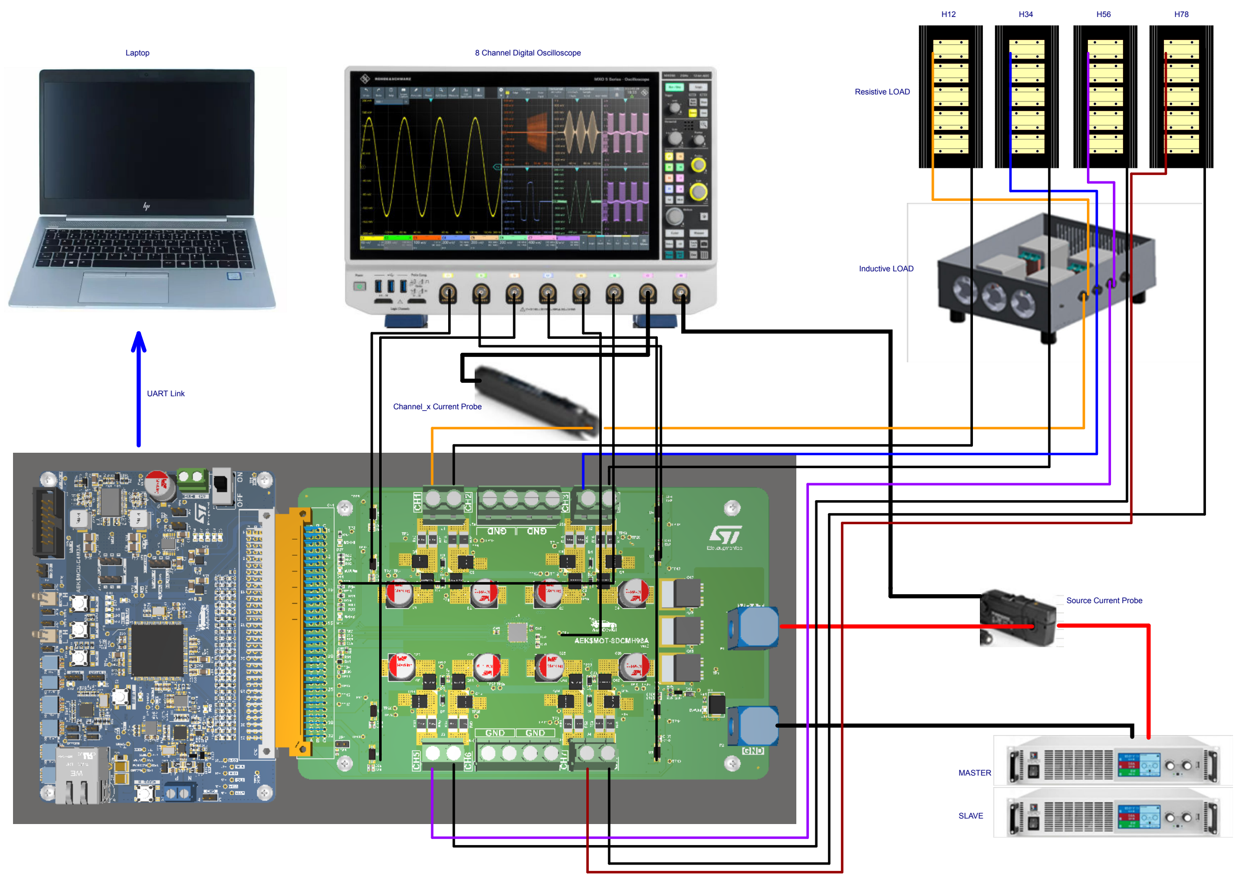
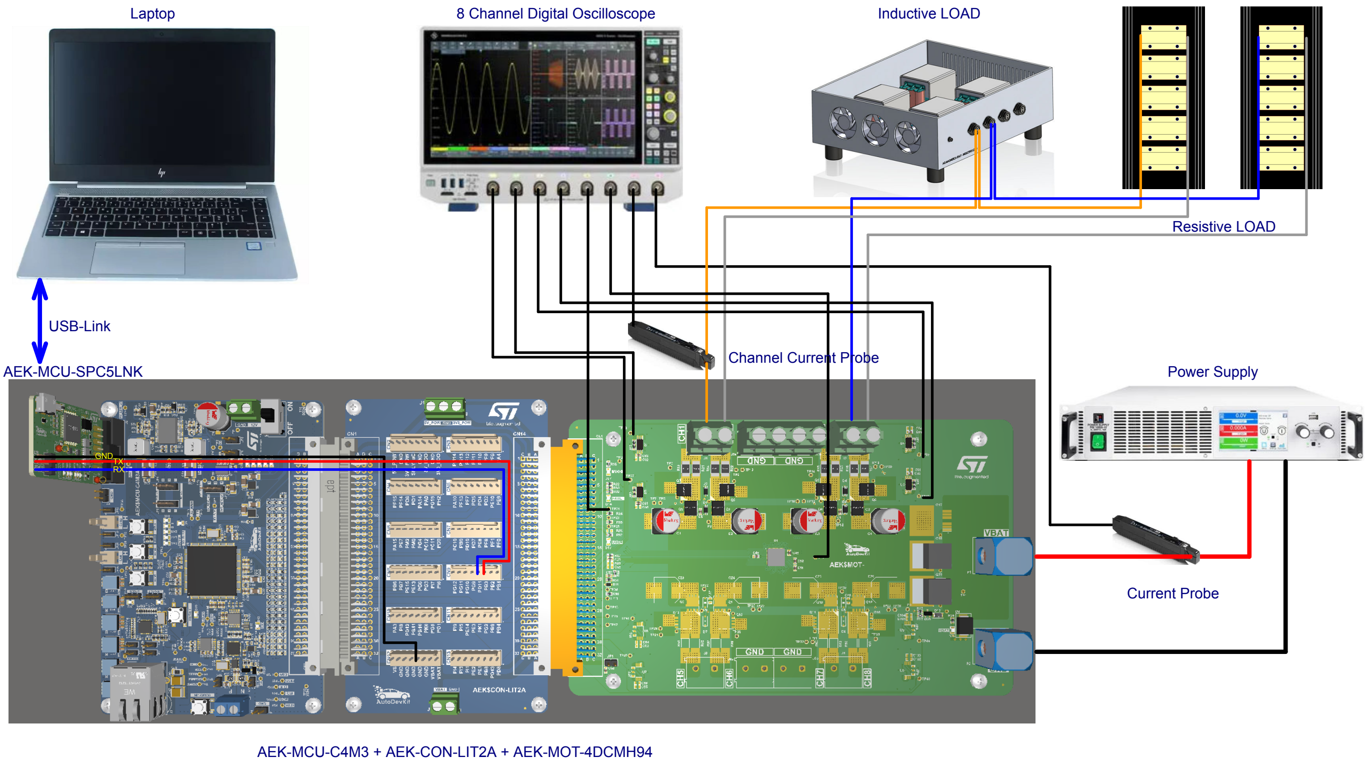


Figure 23. Test setup for the AEK-MOT-4DCMH94



The microcontroller on the AEK-MCU-C4M3 board and the L99MH98/L99MH94 on the motor control boards communicate via SPI. The following images show SPI signals between the microcontroller and the devices in both directions.

Figure 24. SPI signals for L99MH98

Figure 25. **SPI signals for L99MH94**

This oscilloscope captures show the integrity of the SPI bus signals while the motor control boards deliver the maximum power to the loads. The SPI signals are measured using probes connected to channels C1, C2, C3, and C4.

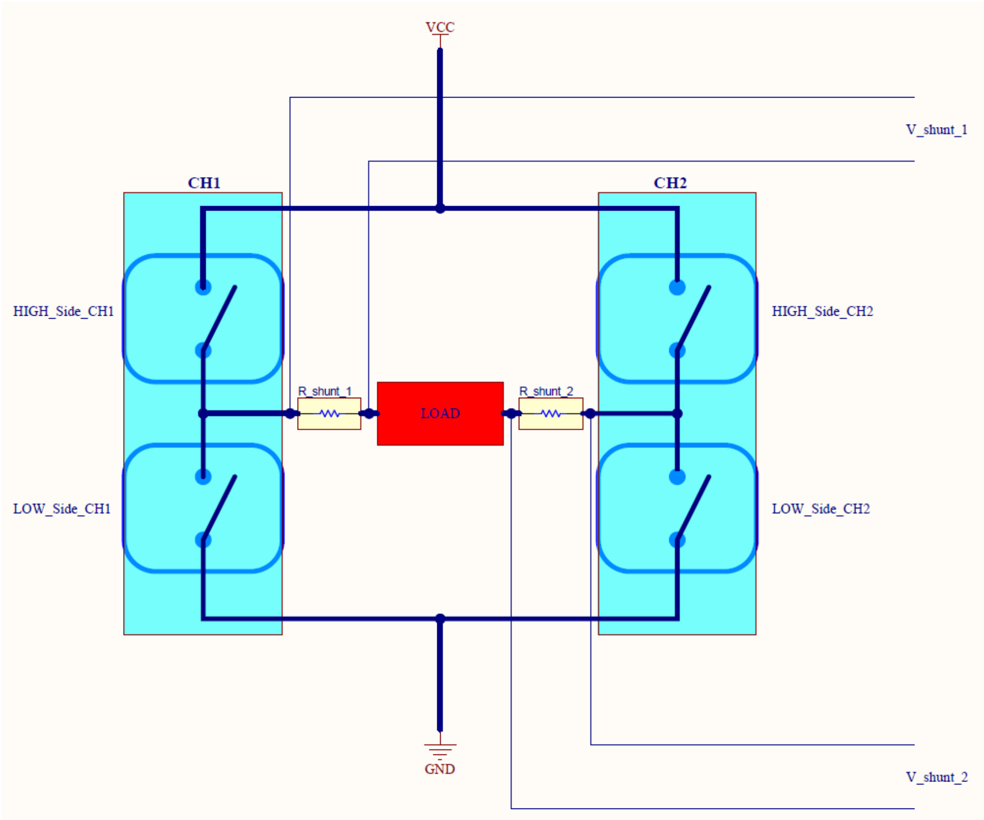
The signal measured by the current probe on channel C8 for the AEK-MOT-8DCMH98 represents the battery current or generator current.

Two/four load modules with heatsinks were assembled in the laboratory to correspond to the two/four H-bridges.

The inductors and resistors were combined to form the resistive-inductive loads required to test the two/four H-bridges and the four/eight half-bridges.

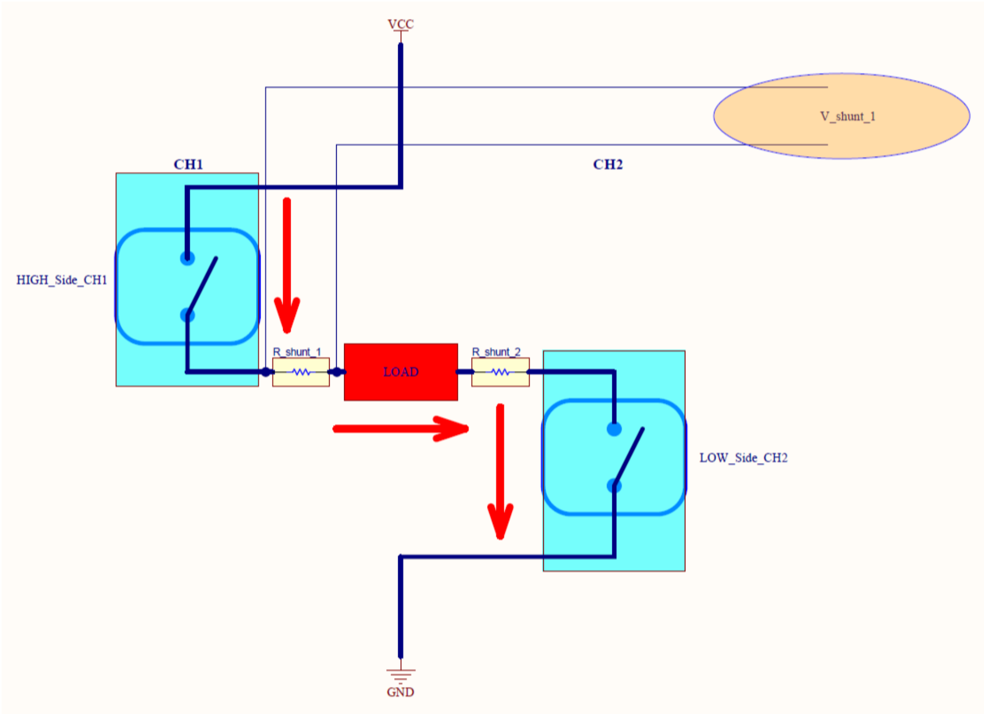
The optimal current measurement configuration is described below, as it closely matches the measurement taken with the current probe. The sensing resistors are connected in series with the load.

Figure 26. **Sensing resistors**



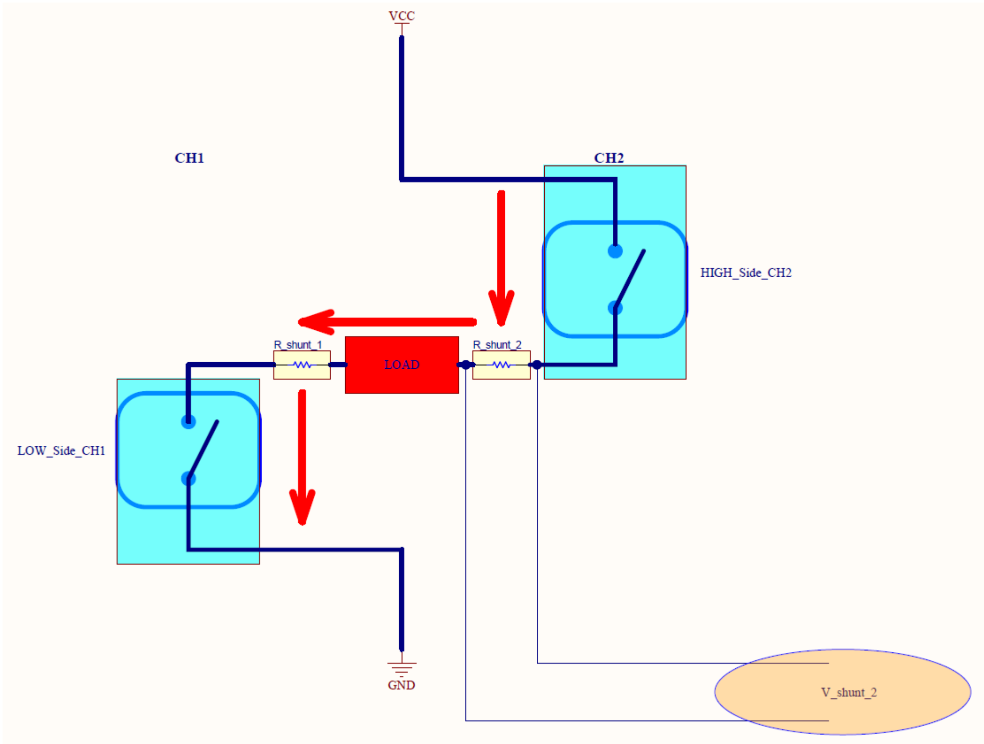
There are two sensing resistors because the current is read in one direction by the first shunt (see the following figure):

Figure 27. **First shunt**



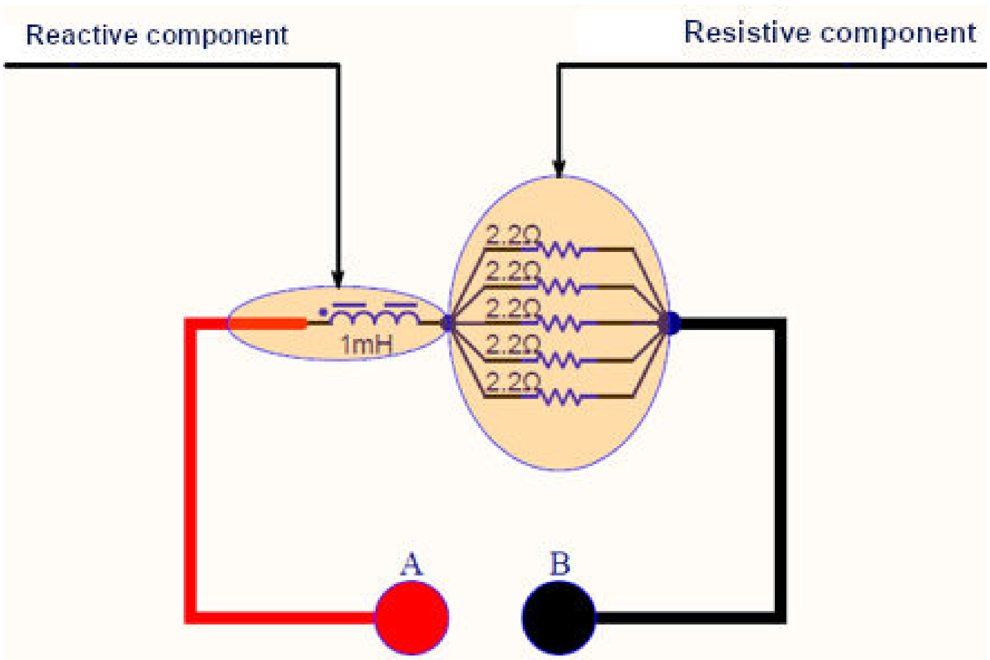
And by shunt two in the opposite direction (see the following figure):

Figure 28. **Second shunt**



To test the boards, we used a load consisting of a 1 mH inductor at 30 A (50 A peak) and five 2.2 Ω, 100 W resistors connected in parallel.

Figure 29. **Test load**



The five 2.2 Ω resistors in parallel give a combined resistance of 0.44 Ω.

From an ideal point of view, with a 14 V DC power supply we should obtain:

$$I = V \div R = 14 \div 0.44 = 31.8A$$

However, from our test acquisitions, we got a current of 30 A_{rms}, which corresponds to a slightly higher total effective resistance (about 0.467 Ω), due to the R_{DSON} of the MOSFETs, the cables connecting the load to the board, and copper losses.

Considering that the inductor and the resistors have small extra parasitic resistance, the actual current at 14 V is about 30 A_{rms}.

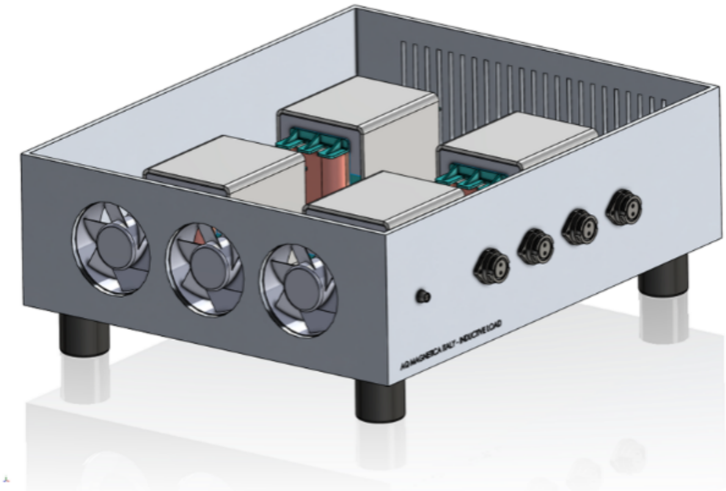
1.9.2 Reactive component of the load

The reactive component consists of an inductor.

The inductor has a core made of sintered ferromagnetic powder, which can withstand an operating frequency of 1 - 20 kHz at 30 A_{rms} with 50 A_{pk}.

Four inductors with ferromagnetic core have been placed in a metal enclosure with forced cooling, as shown in the figure below.

Figure 30. Reactive component

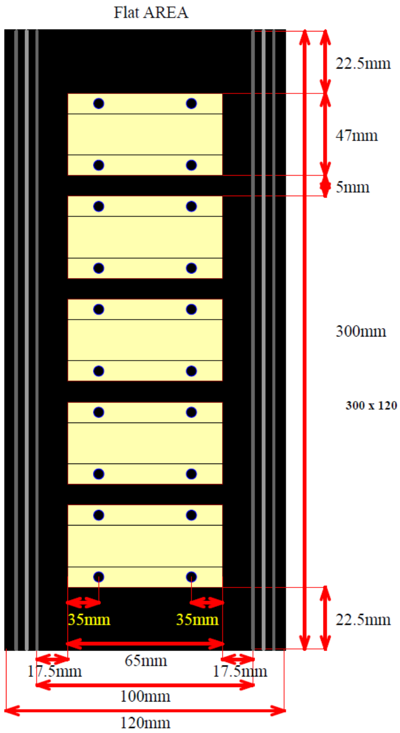


1.9.3 Resistive component of the load

The resistive component consists of five 100 W resistors connected in parallel.

The five resistors are mounted with a thermally conductive layer placed between each armored resistor and the heatsink on a dissipative aluminum profile, as shown in the following figure.

Figure 31. Resistive component



1.9.4 Test results

To measure dissipated temperature, we used a thermal imaging camera.

The thermal images and the corresponding oscilloscope snapshots below are related to the full bridge consisting of channels CH1 and CH2 for the AEK-MOT-8DCMH98 and channels CH1+CH2 and CH3+CH4 with 50% pulse-width modulation (PWM).

In these images, for the AEK-MOT-8DCMH98:

- C1 triggers PWM1 at 10 kHz, duty cycle = 50%
- C2: TP39 = 0 V
- C3: TP3 = VDH = 13.99 V
- C4: TP38 = 1.57 V
- C5: not used for the measurement
- C7: probe measuring the channel current
- C8: probe measuring the battery or generator current
- M1: mathematical function that calculates the current flowing through R_{sns}

Whereas, for the AEK-MOT-4DCMH94:

- C1: TP37
- C2: TP38
- C3: TP39
- C4: TP40
- C5: triggers PWM1 at 10 kHz, duty cycle = 50%
- C6: TP3 = VDH = 13.99 V
- C7: probe measuring channel CH1/CH2 current (CW/CCW)
- C8: probe measuring channel CH3/CH4 current (CW/CCW)
- M1: mathematical function that calculates the current flowing through CH1/CH2
- M2: mathematical function that calculates the current flow through CH3/CH4

Figure 32. AEK-MOT-8DCMH98 thermal image of CH1 and CH2 full bridge at 50% PWM

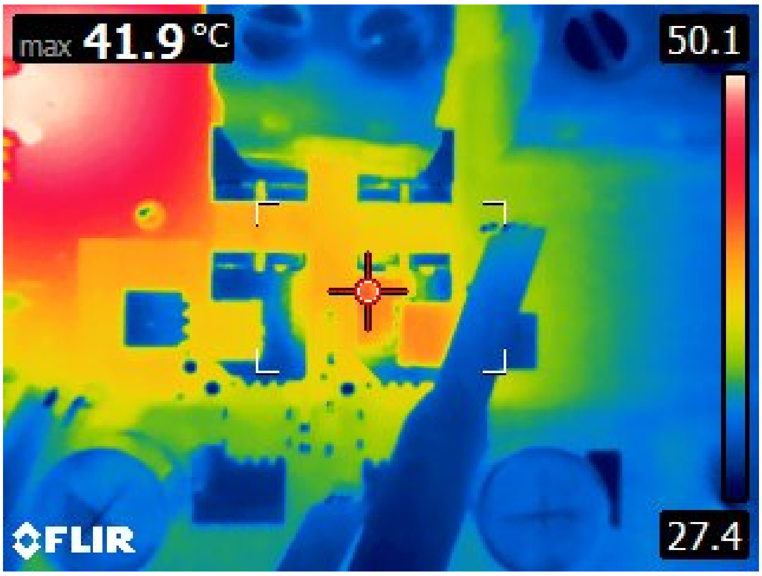


Figure 33. AEK-MOT-8DCMH98 oscilloscope capture of CH1 and CH2 full bridge at 50% PWM

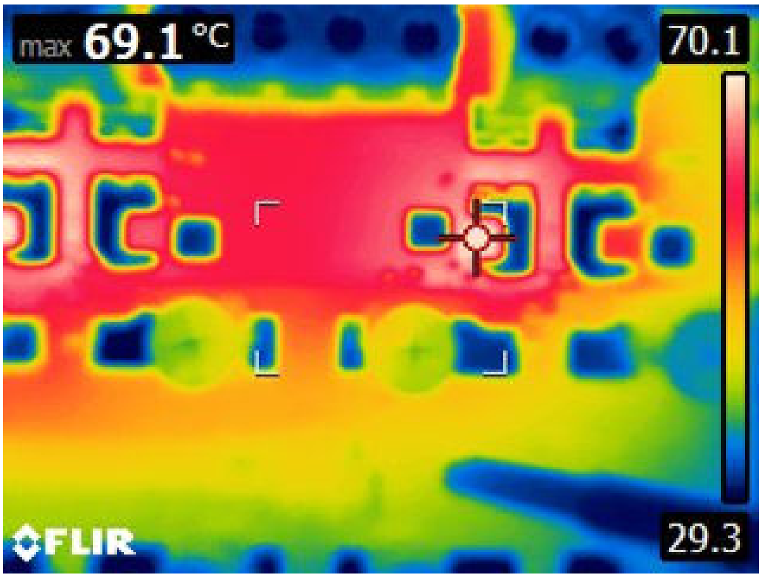


Figure 34. **AEK-MOT-4DCMH94 thermal image of CH1+CH2 and CH3+CH4 full bridge at 50% PWM**

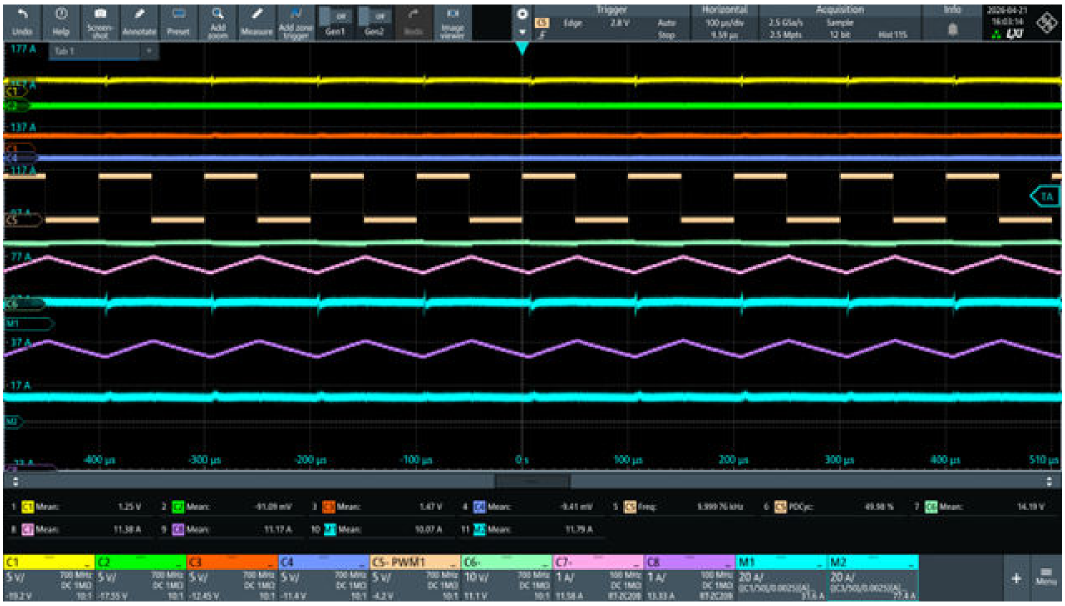


Figure 35. **AEK-MOT-4DCMH94 oscilloscope capture of CH1+CH2 and CH3+CH4 full bridge at 50% PWM**

The thermal images and the corresponding oscilloscope snapshots below are related to the full bridge consisting of channels CH1 and CH2 for the AEK-MOT-8DCMH98 and channels CH1+CH2 and CH3+CH4 for the AEK-MOT-4DCMH94 with 75% pulse-width modulation (PWM).

In these images, for the AEK-MOT-8DCMH98:

- C1 triggers PWM1 at 10 kHz, duty cycle = 75%
- C2: TP39 = 0 V
- C3: TP3 = VDH = 13.99 V
- C4: TP38 = 2.51 V
- C5: not used for the measurement
- C7: probe measuring the channel current
- C8: probe measuring the battery or generator current
- M1: mathematical function that calculates the current flowing through R_{sns}

Figure 36. **AEK-MOT-8DCMH98 thermal image of CH1 and CH2 full bridge at 75% PWM**

Figure 37. **AEK-MOT-8DCMH98 oscilloscope capture of CH1 and CH2 full bridge at 75% PWM**

Whereas, for the AEK-MOT-4DCMH94:

- C1: TP37
- C2: TP38
- C3: TP39
- C4: TP40
- C5: triggers PWM1 at 10 kHz, duty cycle = 75%
- C6: TP3 = VDH = 14.09 V
- C7: probe measuring channel CH1/CH2 current (CW/CCW)
- C8: probe measuring channel CH3/CH4 current (CW/CCW)
- M1: mathematical function that calculates the current flowing through CH1/CH2
- M2: mathematical function that calculates the current flow through CH3/CH4

Figure 38. **AEK-MOT-4DCMH94 thermal image of CH1+CH2 and CH3+CH4 full bridge at 75% PWM**

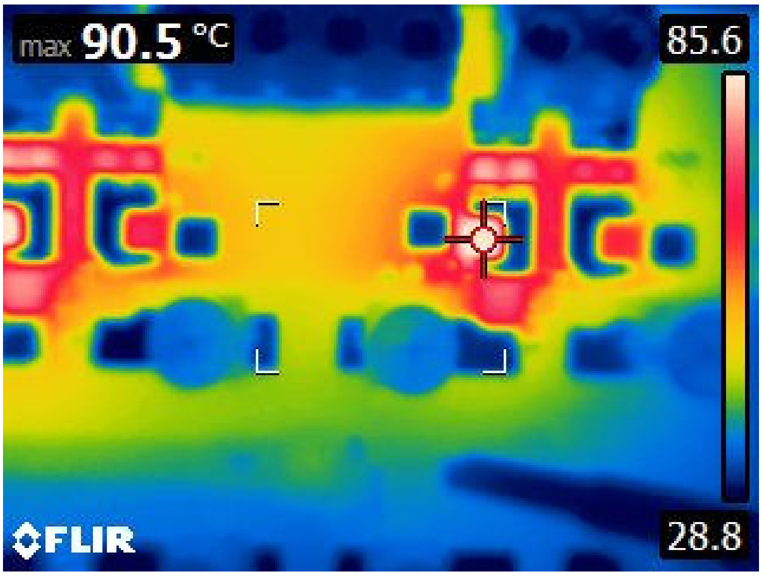
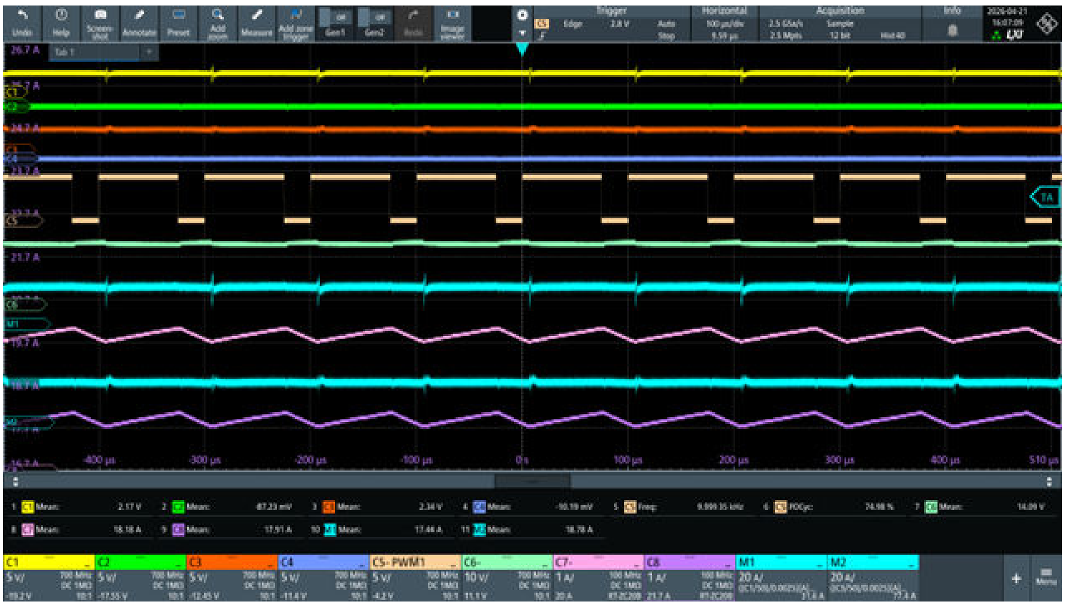


Figure 39. **AEK-MOT-4DCMH94 oscilloscope capture of CH1+CH2 and CH3+CH4 full bridge at 75% PWM**



Below are the thermal images of the 4 full bridges (CH1+CH2, CH3+CH4, CH5+CH6, CH7+CH8) related to the AEK-MOT-8DCMH98 and the 2 full bridges (CH1+CH2, CH3+CH4) at 100% driven at odd and even channels related to the AEK-MOT-4DCMH94, at 100%.

These figures also show the temperature rise of the MOSFETs and the copper trace that supplies power to the H-bridges.

Figure 40. **AEK-MOT-8DCMH98 thermal image of the 4 full bridges at 100% PWM**

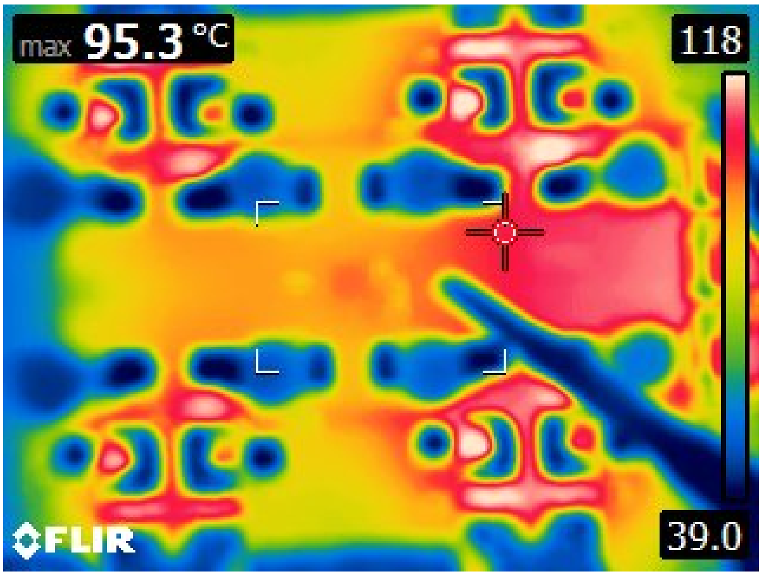
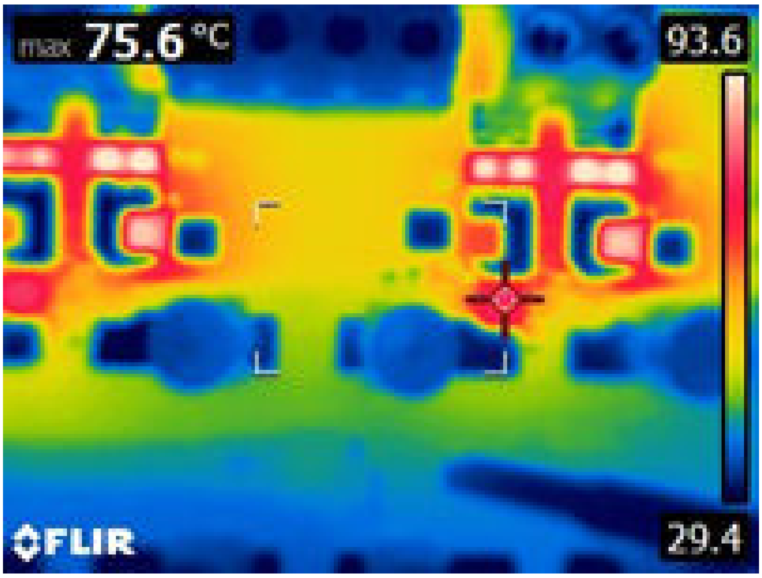


Figure 41. **AEK-MOT-4DCMH94 thermal image of the 2 full bridges (CH1+CH2 and CH3+CH4) at 100% PWM**



The full bridges have been connected to the resistive-inductive load at the maximum power for a duration of 300 seconds for the AEK-MOT-8DCMH98 board and 60 seconds for the AEK-MOT-4DCMH94.

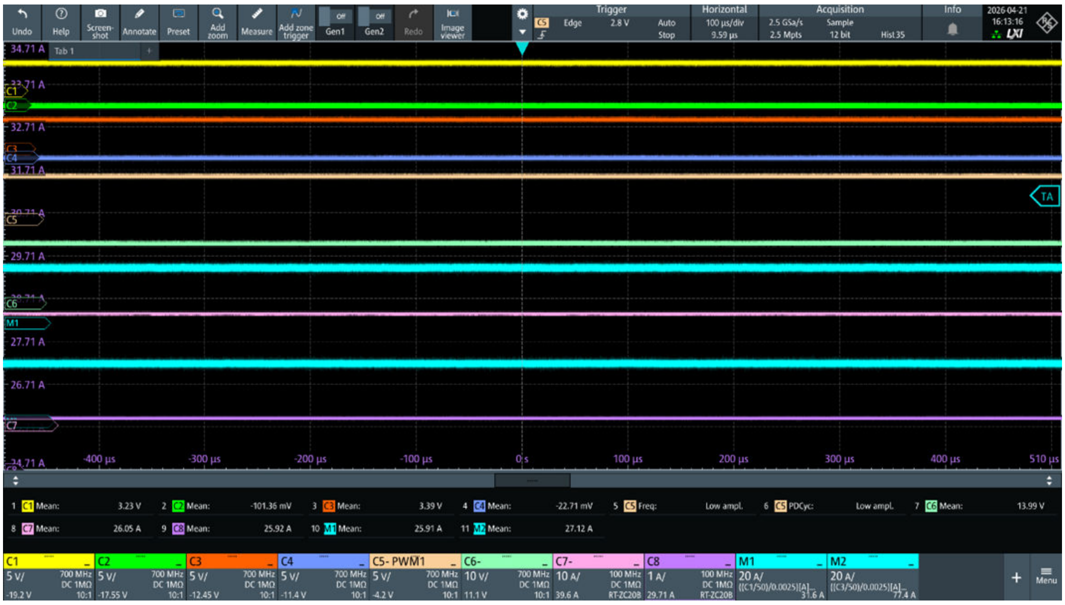
The images below have been acquired with the oscilloscope and show the full bridges at the maximum power.

For the AEK-MOT-8DCMH98, the oscilloscope channels C1, C2, C3, and C4 are respectively the outputs of the operational amplifiers U2, U4, U6, and U8 that perform current sensing through the sensing resistors.

Figure 42. **AEK-MOT-8DCMH98 oscilloscope capture of the 4 full bridges at 100% PWM**

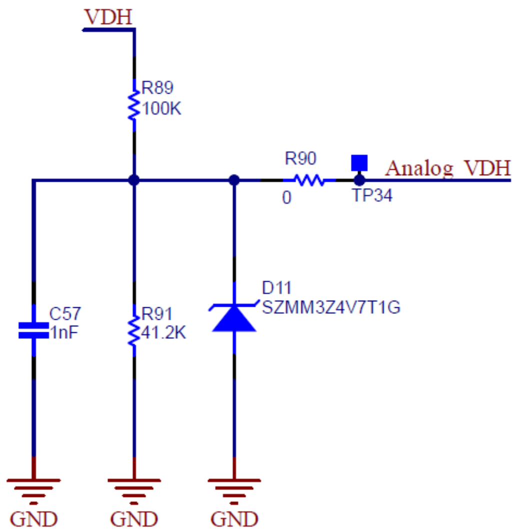
For the AEK-MOT-4DCMH94, instead, the oscilloscope channels C1 and C3 are respectively the outputs of the operational amplifiers U2 and U4 that perform current sensing through the sensing resistors in clockwise direction, while the oscilloscope channels C2 and C4 are respectively the outputs of the operational amplifiers U3 and U5 that perform current sensing through the sensing resistors in counterclockwise direction.

Figure 43. **AEK-MOT-4DCMH94 oscilloscope capture of the 2 full bridges (CH1+CH2 and CH3+CH4) at 100% PWM**



Channel C5 for the AEK-MOT-8DCMH98 and channel C6 for the AEK-MOT-4DCMH94, the VDH (the voltage at the output of the MOSFET group used for reverse battery protection) is measured. This voltage is read by the MCU A/D converter through a conditioning circuit (R89, R91, C57, D11, and R90).

Figure 44. VDH schematic snapshot



2 AutoDevKit ecosystem

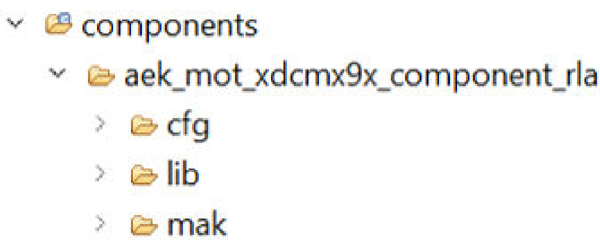
The application development employing our L99MH9x family evaluation boards takes full advantage of the AutoDevKit ecosystem, whose basic components are:

- AutoDevKit Studio IDE (STSW-AUTODEVKIT)
- OpenOCD programmer and debugger

2.1 aek_mot_xdcmx9x_component_rla folder structure

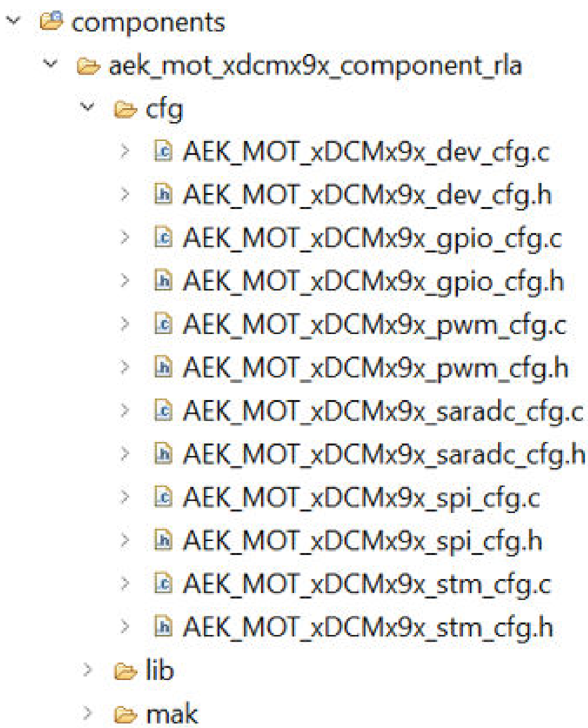
For the AEK-MOT-xDCMx9x component, the code is split into the following folders:

Figure 45. Components folder



The cfg folder contains configuration files. The content of each file depends on the choices made by the user in the project and on the specific resources that are allocated, such as pins and peripherals. The files in the cfg directory are:

Figure 46. aek_mot_xdcmx9x_component_rla



The lib folder contains library files that remain unchanged regardless of the user's selections, peripherals, or allocated pins. Within the lib folder, files are spit into the include folder (header files, .h) and the src folder (source files, .c):

Figure 47. Include folder

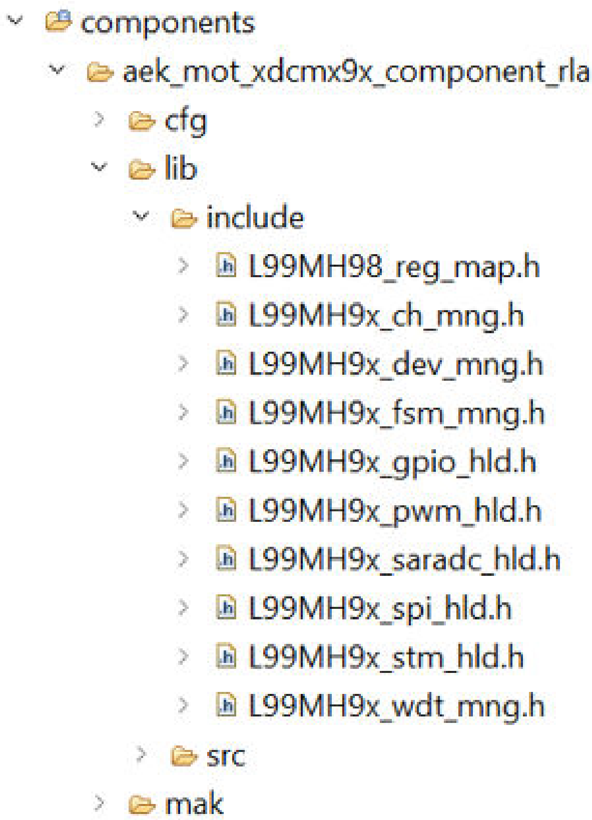
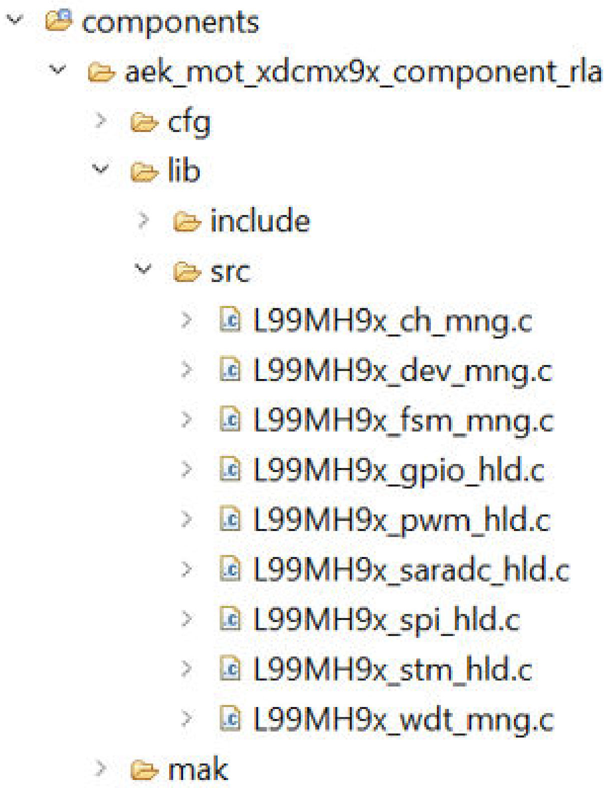


Figure 48. **Src folder**



Files with the “_mng” suffix are the highest-level files available to the user:

- dev_mng: Functions for controlling and configuring devices (a specific board allocated by the user).
- ch_mng: Functions for controlling and configuring device channels.
- fsm_mng: Functions for controlling and verifying the finite state machine (FSM) of devices.
- wdt_mng: Functions for controlling the watchdog mechanism for devices.

The remaining files have the “_hld” suffix, which stands for “high-level driver.” These files define intermediate-level functions, which are called within the _mng files, to configure and manage the drivers for various peripherals (GPIO, PWM, SARADC, SPI, STM).

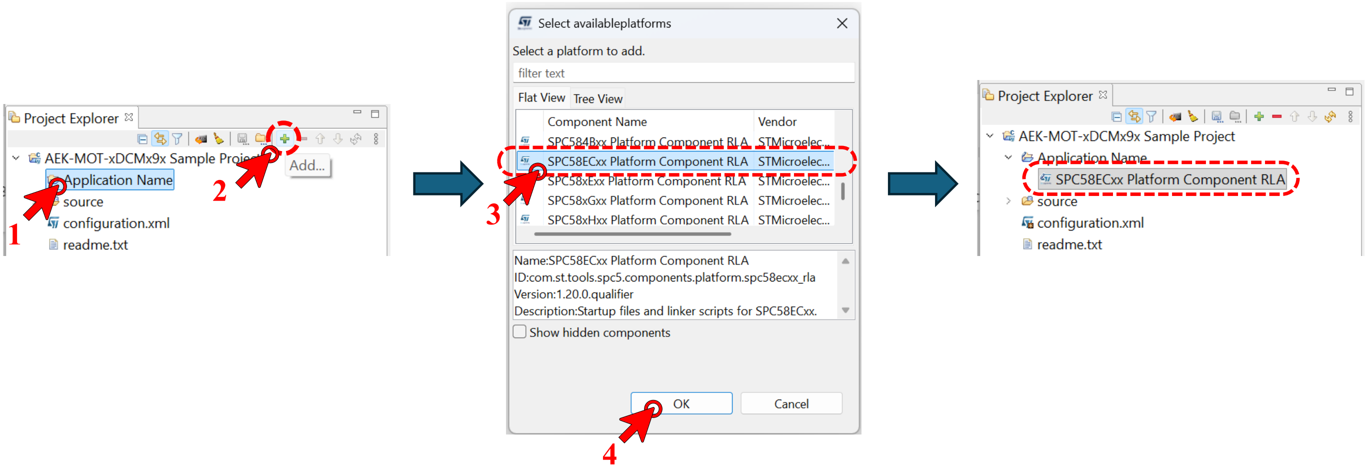
Finally, the reg_map.h file is in the include folder within lib. This file defines the structure of the device registers, and the masks required to read or write their contents.

2.2 Using the L99MH9x family motor control boards in AutoDevKit

From AutoDevKit release 2.8.1 on, the AEK-MOT-8DCMH98 and AEK-MOT-4DCMH94 boards can be used through the related component, only in projects with microcontrollers from the SPC58ECxx family. Therefore, the preliminary steps to add and use the board in a blank project are as follows:

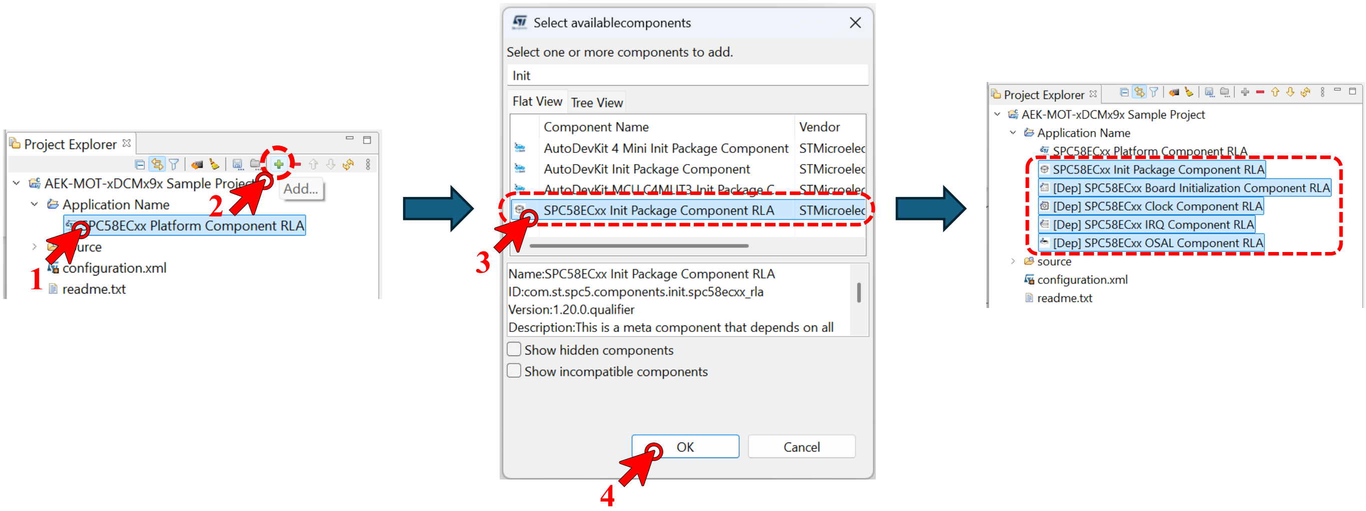
Step 1. Click on the items highlighted in the image below, following the numbered sequence, to add the SPC58ECxx Platform Component RLA:

Figure 49. Adding SPC58ECxx Platform Component RLA



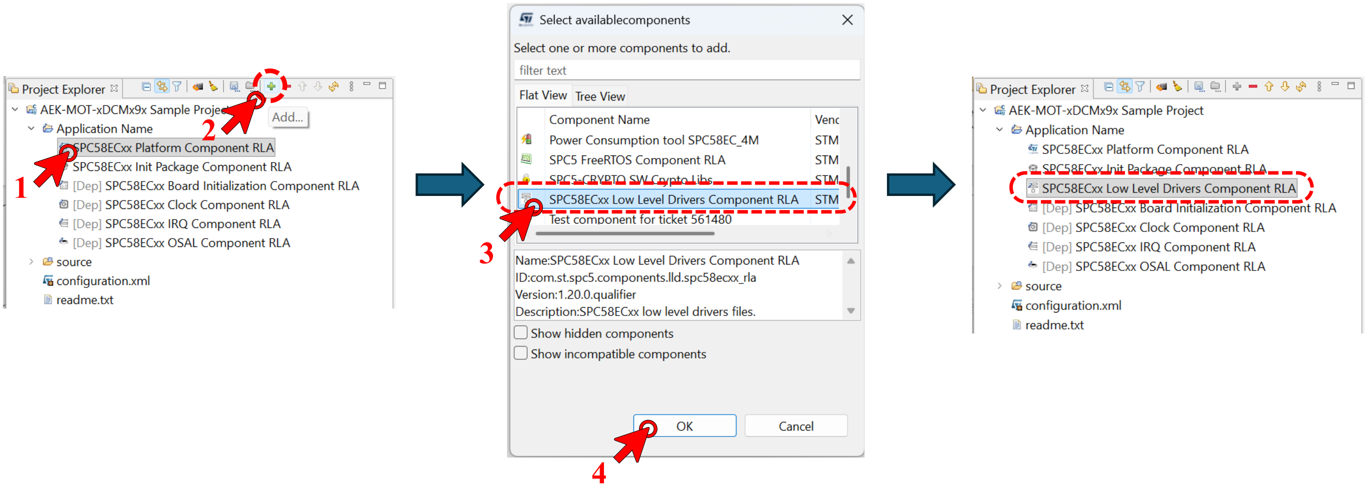
Step 2. Click on the items highlighted in the image below, following the numbered sequence, to add the SPC58ECxx Init Package Component RLA, which automatically adds Board Initialization, Clock, IRQ and OSAL components to the project.

Figure 50. Adding SPC58ECxx Init Package Component RLA



Step 3. Add SPC58ECxx Low Level Drivers Component RLA by following the same approach.

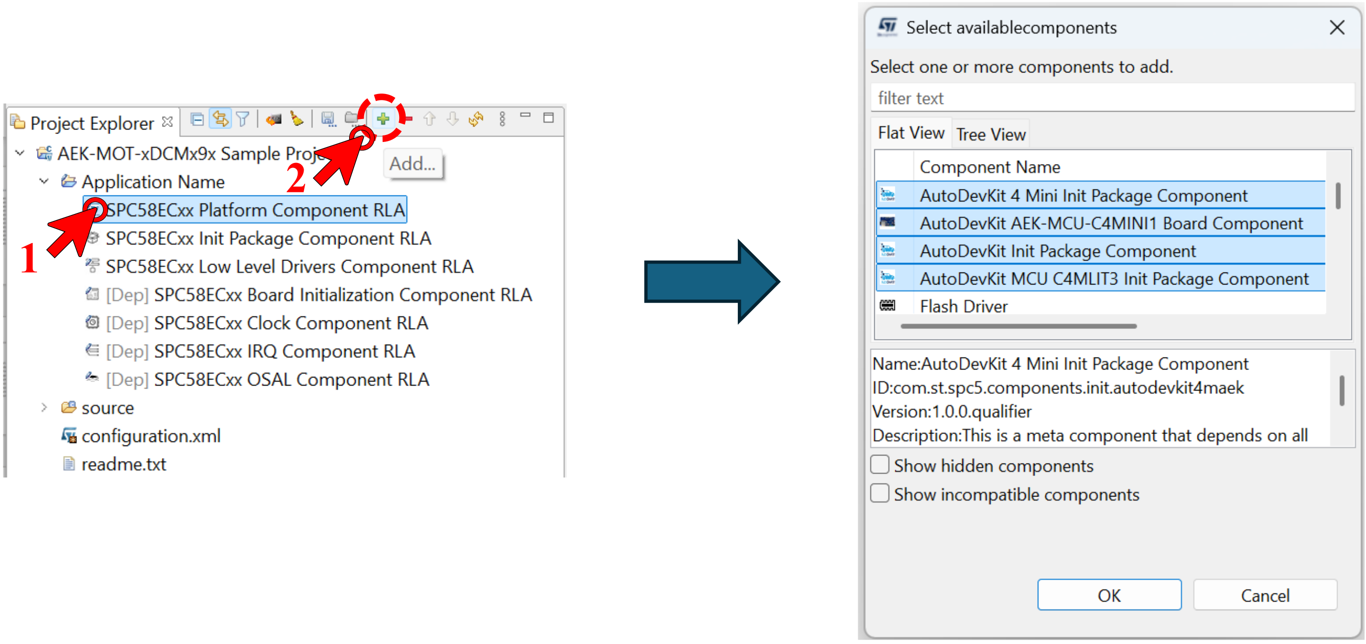
Figure 51. Adding SPC58ECxx Low Level Drivers Component RLA



Step 4. Choose and add a component among the ones listed below, depending on the SPC58ECxx MCU board you are using:

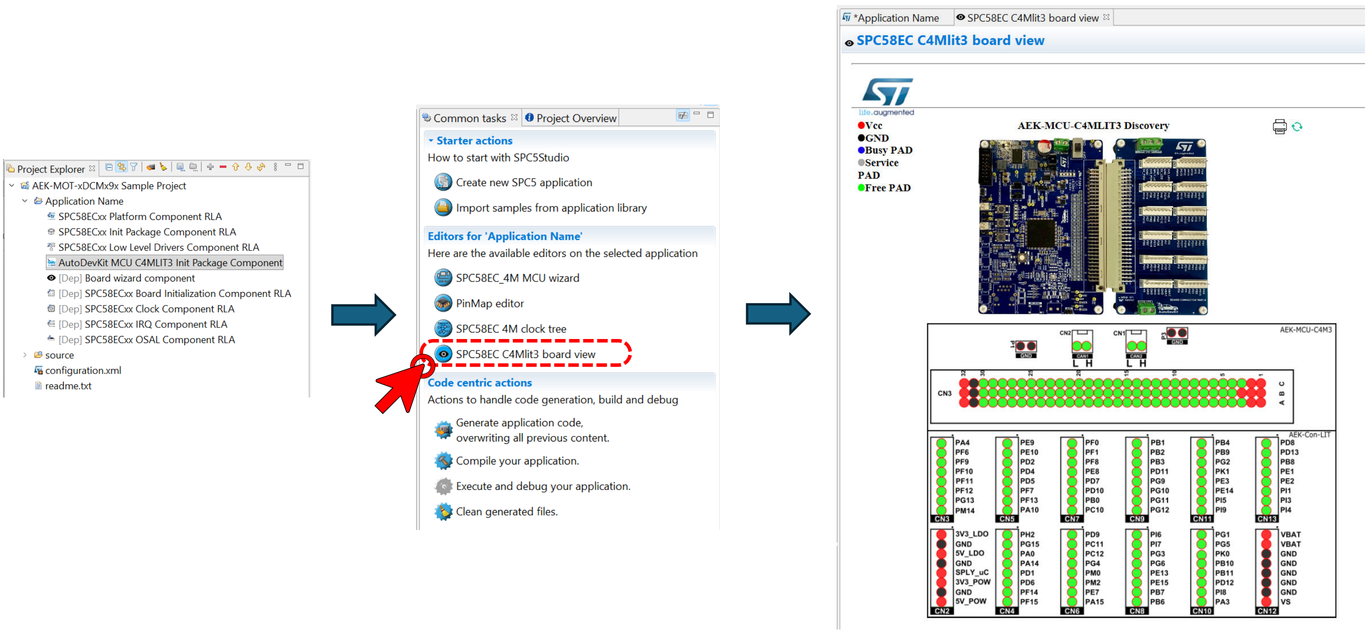
- AutoDevKit Init Package Component for AEK-MCU-C4MLIT1
- AutoDevKit 4Mini Init Package Component or AutoDevKit AEK-MCU-C4MINI1 Board Component for AEK-MCU-C4MINI1
- AutoDevKit MCU C4MLIT3 Init Package Component for AEK-MCU-C4MLIT3

Figure 52. Example using different MCU boards



The example below shows the usage of AutoDevKit MCU C4MLIT3 Init Package Component related to AEK-MCU-C4MLIT3, exploiting the Board View, which allows seeing the mapped pins on the MCU board.

Figure 53. Example using AEK-MCU-C4MLIT3



Step 5. Add AEK-MOT-xDCMx9x Component RLA component, which will be added to the other components imported so far:

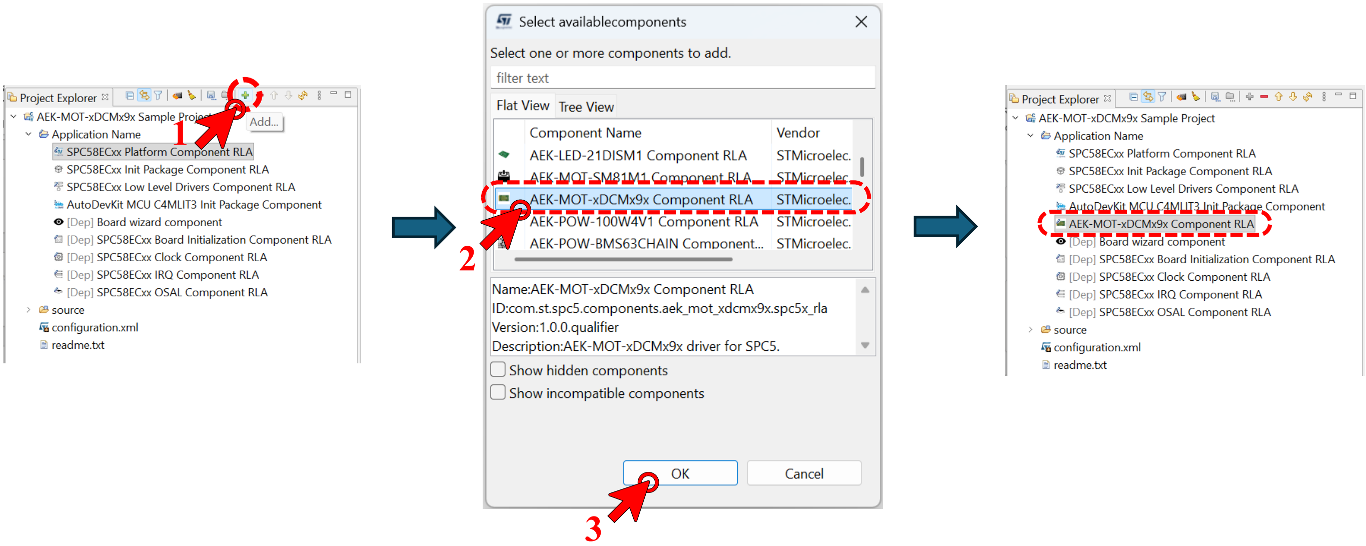


Figure 54. Adding AEK-MOT-xDCMx98xcomponent

By clicking on the AEK-MOT-xDCMx9x Component RLA, the AEK-MOT-xDCMx9x corresponding page will be opened to configure one or more boards to be used in the application:

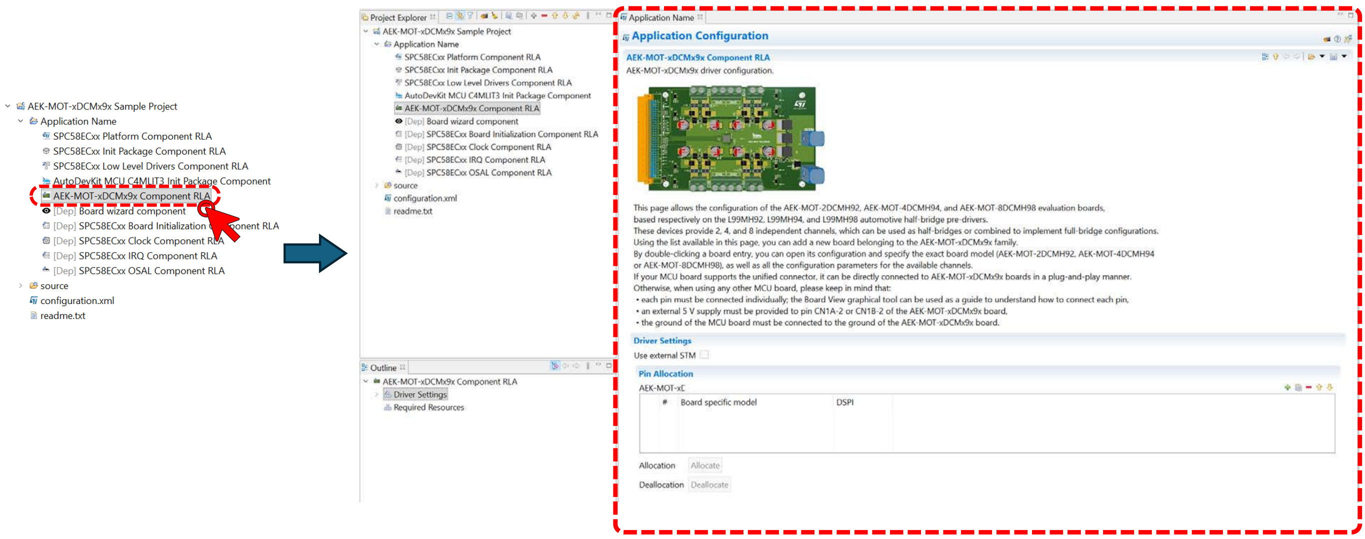
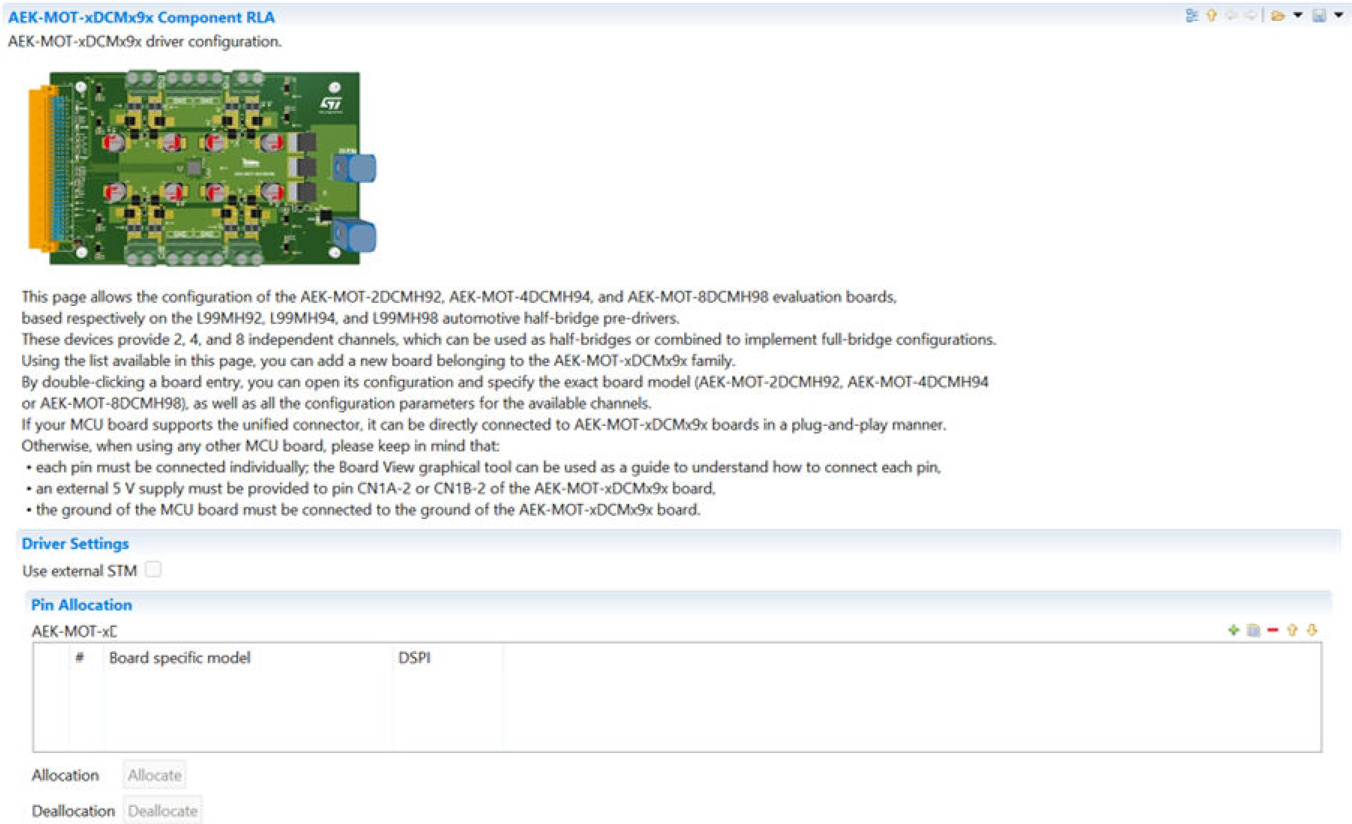


Figure 55. Application configuration page

Step 6. Configure the board according to your application needs.

At the top of the configuration page, an introductory section includes an image of the board and a brief description of its main features. The next section is the configuration area, which contains graphical elements that allow the user to customize the number of boards used in the project and their functionalities. At the bottom, two buttons start the allocation and deallocation procedures.
The allocation procedure configures the microcontroller pins and peripherals required for the AEK-MOT-xDCMx9x operation. The number of resources used, and the configurations applied, depends on the number of boards selected and the customizations made by the user. Deallocation is the reverse process. It cancels all operations performed during allocation, frees the pins and peripherals used, and restores every configuration applied.

Figure 56. Pin allocation

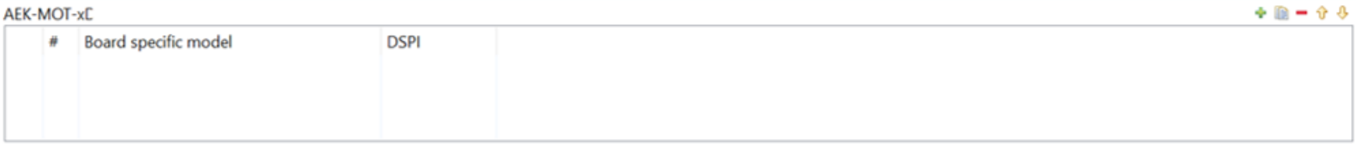


– **Use External STM**: this is a check box with two possible options: selected and not selected, with the latter as the default. For normal operation, the device periodically requires a watchdog signal, transmitted through an SPI frame. If the Use External STM field is not selected, during allocation, an STM peripheral is reserved and configured in the microcontroller. This periodically triggers a callback to send the watchdog signal to all boards in the application.
Conversely, when the Use External STM field is selected, no STM peripheral is allocated during the allocation phase. This is because the use of an external mechanism, such as when the user intends to use FreeRTOS™ to schedule periodic tasks, is assumed.
The Use External STM field is interactive, and its value can be modified only if:
  - The board list is not empty and contains at least one element.
  - The allocation procedure has not yet been performed.
  - The deallocation procedure has been performed after allocation.

Below is a list of all configuration elements that the user can interact with. The results of each configuration are described according to the assigned values.

- **AEK-MOT list**
  This is the main component element, which consists of the list of all the boards you want to use in your application. The list is represented by a table that contains as many rows as the boards to be used. The two columns represent the board number (starting from 0) and the identification of the DSPI peripheral used for communication.

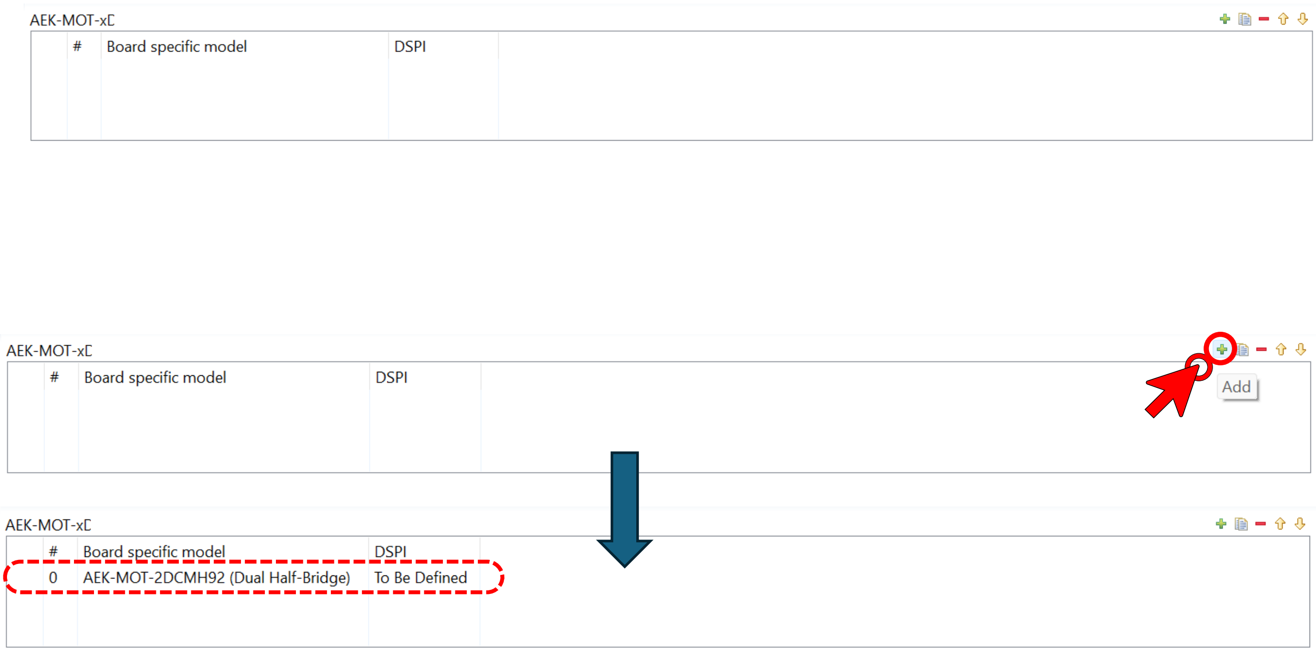
Figure 57. List of boards to be used



In the top-right corner, there are various buttons for different specific functions.

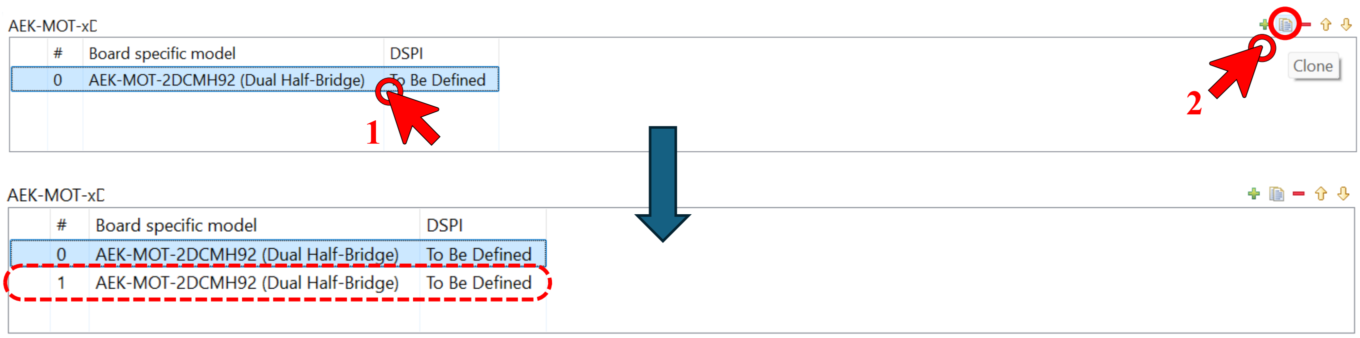
- **Add**: adds a new board to the default configuration

Figure 58. Add button



- **Clone**: by selecting a row and clicking on Clone, the row is cloned, keeping the same configuration

Figure 59. Clone button

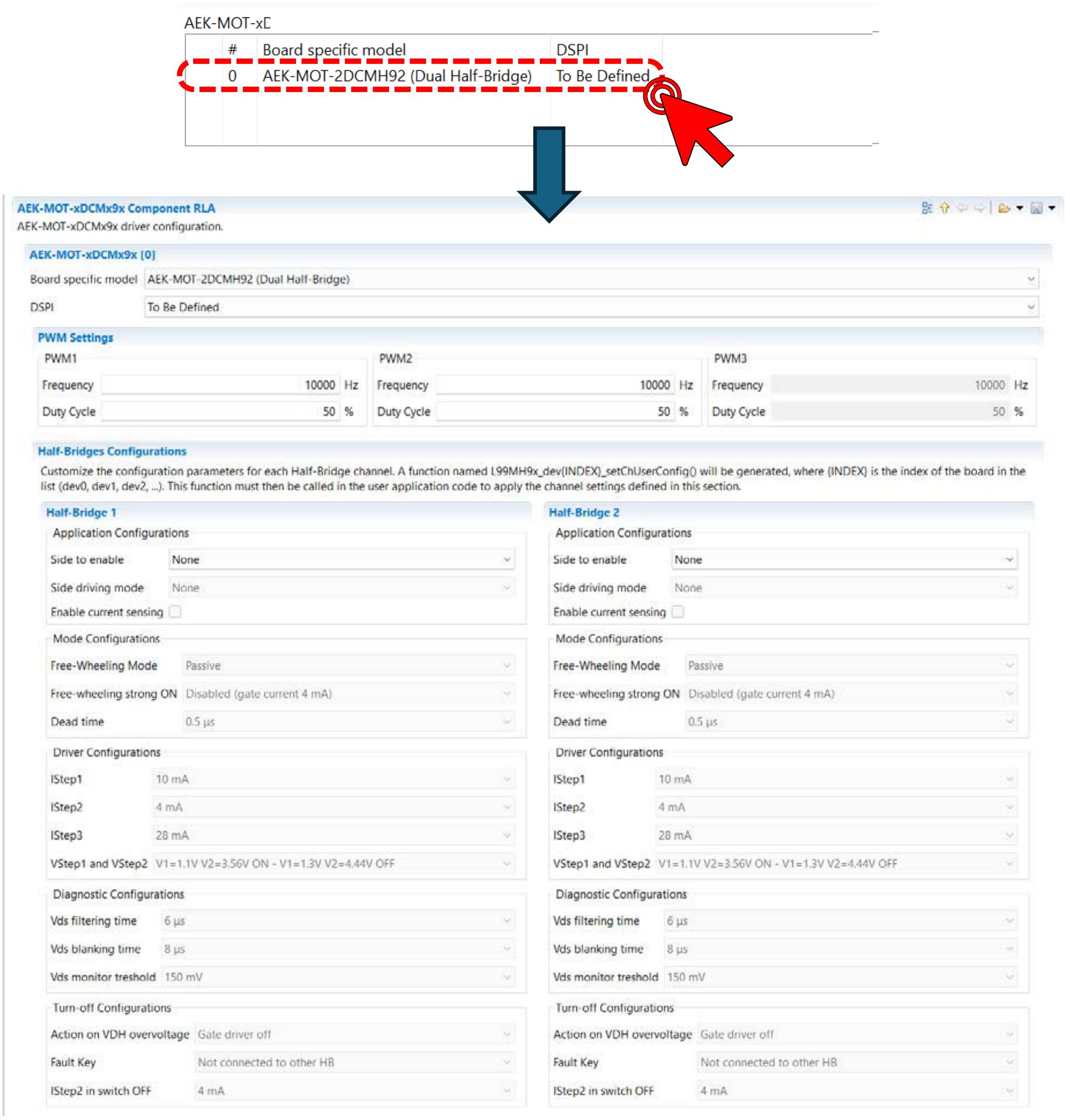


- **Remove:** selecting a row and clicking on Remove, the line (and, consequently, the board) is removed.

Figure 60. Remove button

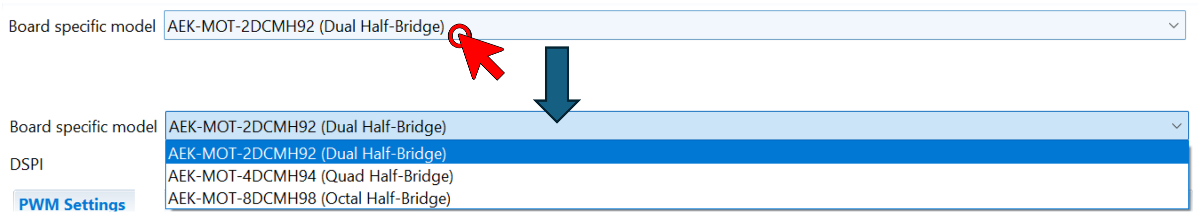
- **Move up/Move down:** the last two icons (the two arrows), move the selected board up or down in the list. Select a board and double-click the related row to access the configuration page for that specific board, as shown in the figure below.

Figure 61. Board configuration page



The board specific model field lists all the available boards with the related number of configurable PWMs and channels, which differ according to the model chosen (see figures below).

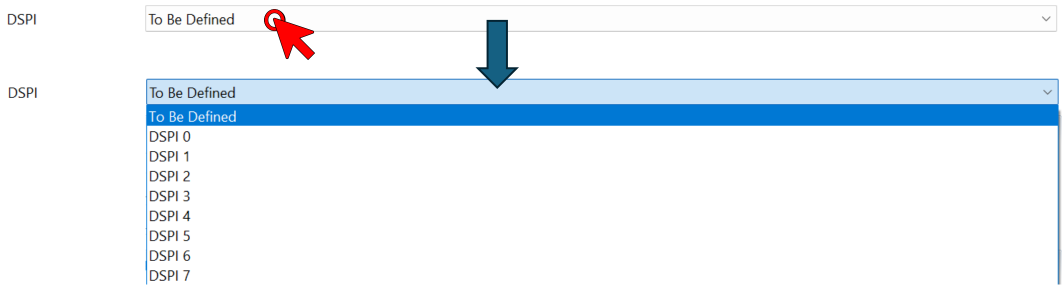
Figure 62. Board specific model field



All configuration elements for each specific board are listed and described below:

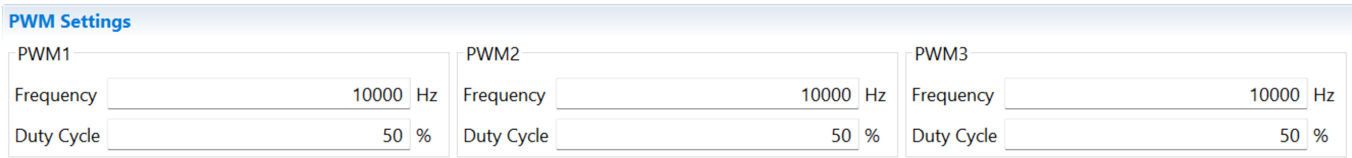
- **DSPI**: DSPI is an enumerative element that indicates the SPI peripheral of the microcontroller to use for communication with the board. The initial value is “To be defined.” When you click on the element, a drop-down menu shows a list of all available SPI peripherals in the microcontroller. You can select the same DSPI peripheral for multiple boards at the same time to use it in shared mode, leveraging the mechanism provided by the SPI protocol.

Figure 63. DSPI selection



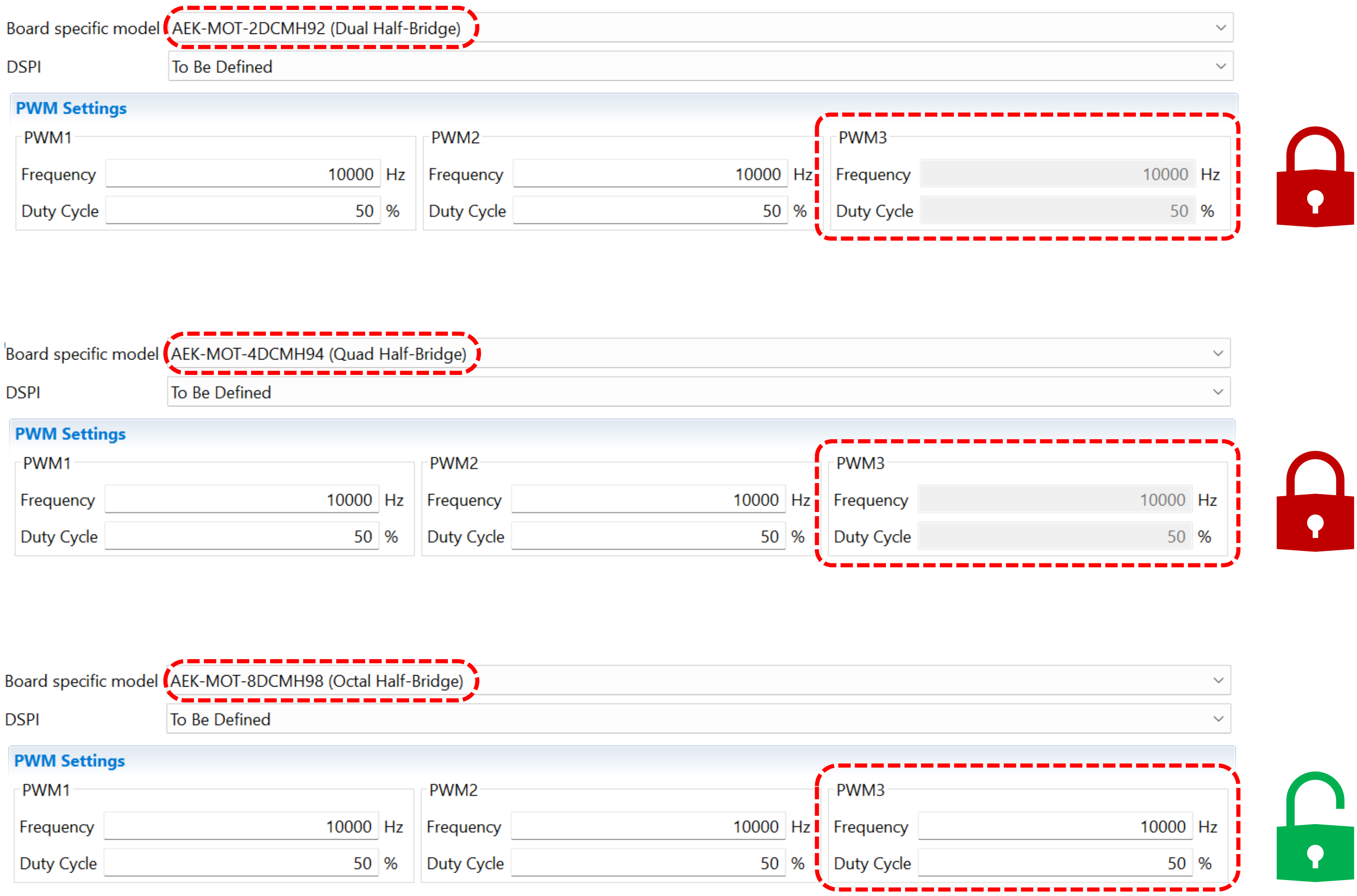
- **PWM Settings:** The PWM settings box allows adjusting of the frequency in Hertz for the three PWM signals. By default, the frequencies are set to 10 000, 15 000, and 20 000 Hertz, respectively.

Figure 64. **PWM settings**



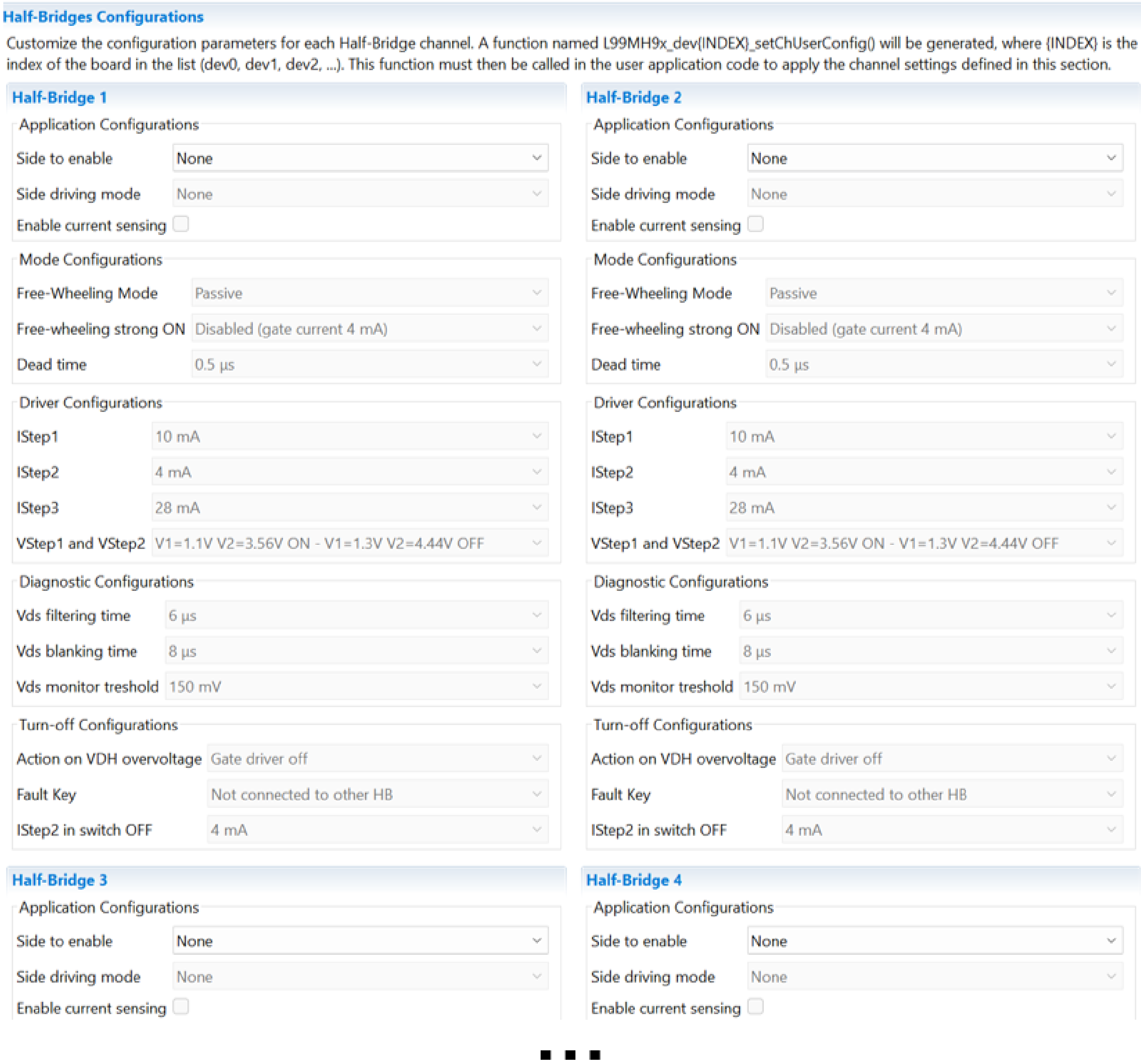
Note: The different board models support different configurable PWMs. The AEK-MOT-8DCMH98 supports 3 PWMs, while the other boards of the same family support only two PWMs. Therefore, changing the board model affects the number of PWMs available.

Figure 65. **Available PWMs**



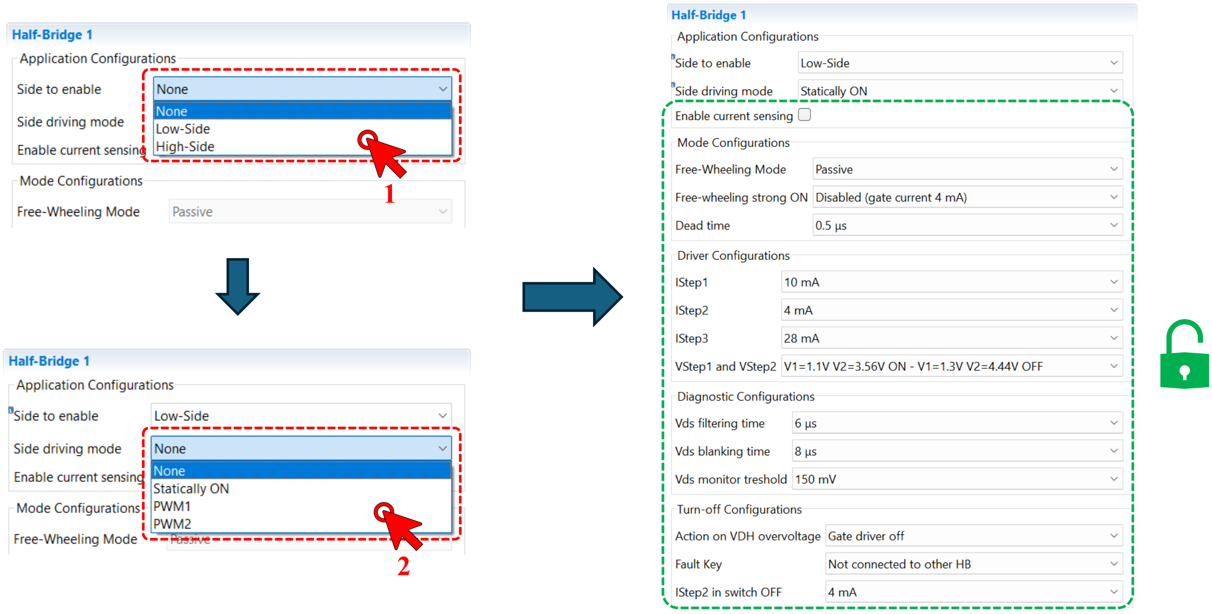
The image below shows the half-bridge configuration options for each channel.

Figure 66. Channel configuration



Setting “Side to enable” and “Side driving mode” fields with values different from “None” activates that Half-Bridge and allows customizing all the other configuration fields.

Figure 67. Channel configuration

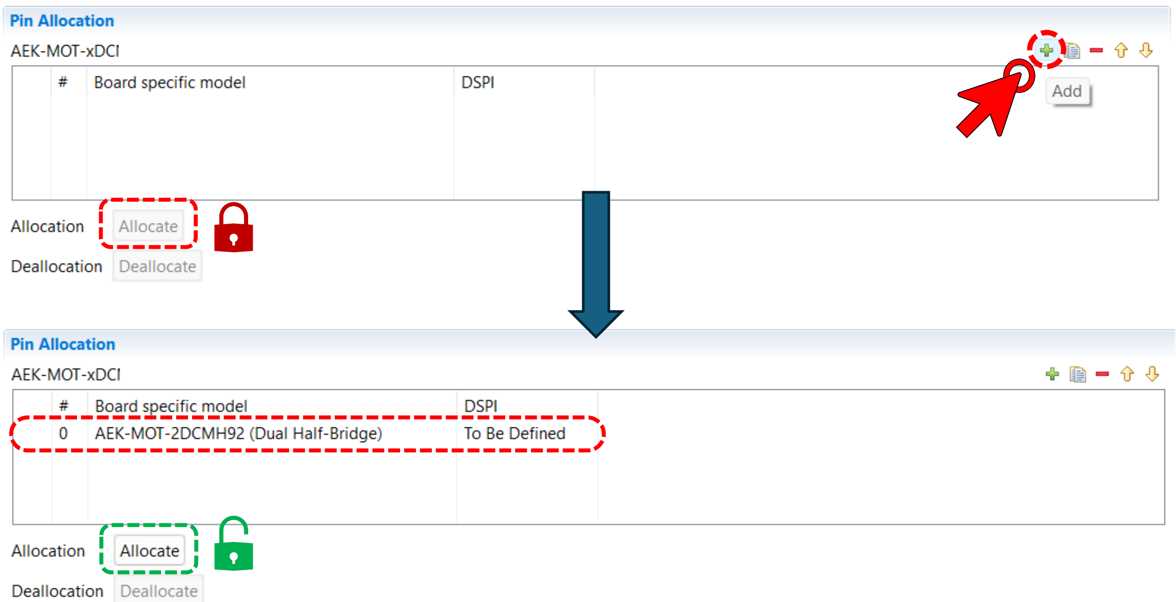


The functionality of each parameter is detailed in the device datasheet. Fields are preconfigured by default with specific values selected to ensure channel operation with the widest range of possible loads. The user can configure each field with the required value.

2.2.1 Allocation and deallocation procedure

The allocate and deallocate buttons are initially unavailable. When at least one board is added to the board list, the allocation button is enabled.

Figure 68. Allocation enabled



If one or more boards are not correctly configured, clicking the allocation button does not start the procedure. Instead, an error message appears, indicating the board that is not correctly configured, and the field that prevents allocation. The following section shows some error messages and their causes:

Figure 69. Allocation failed for wrong DSPI configuration

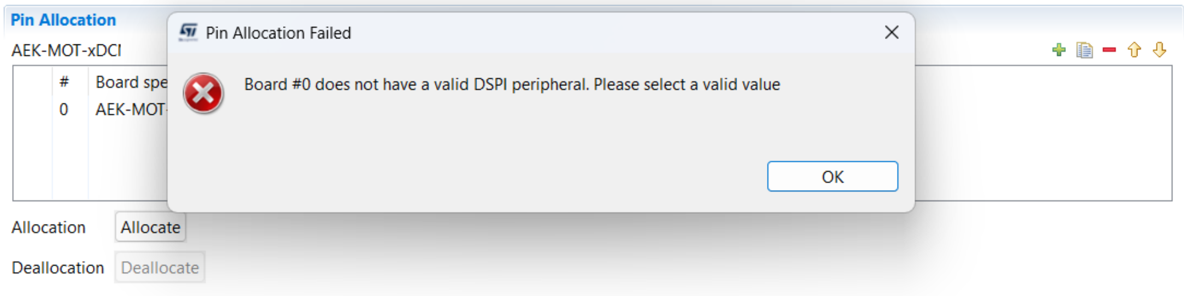
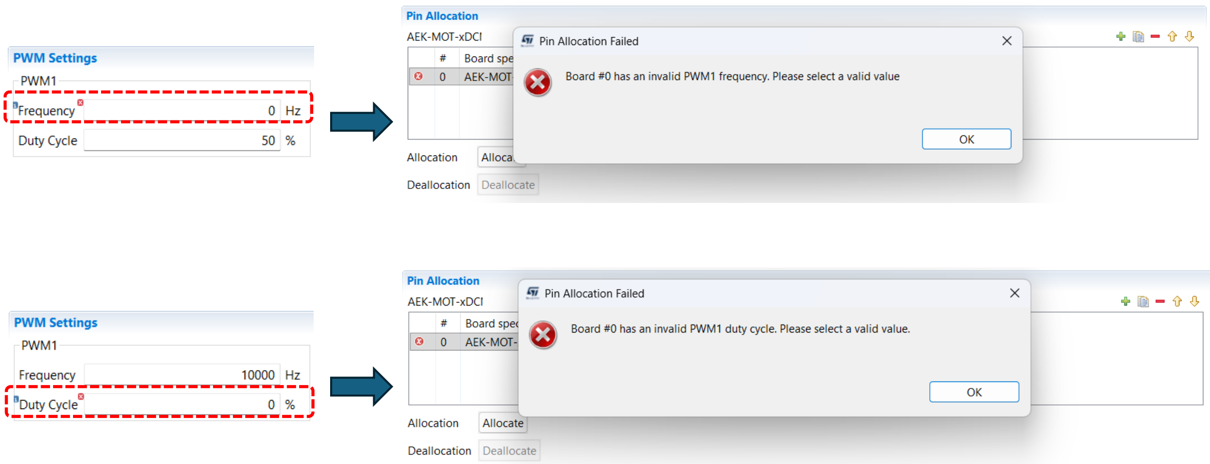
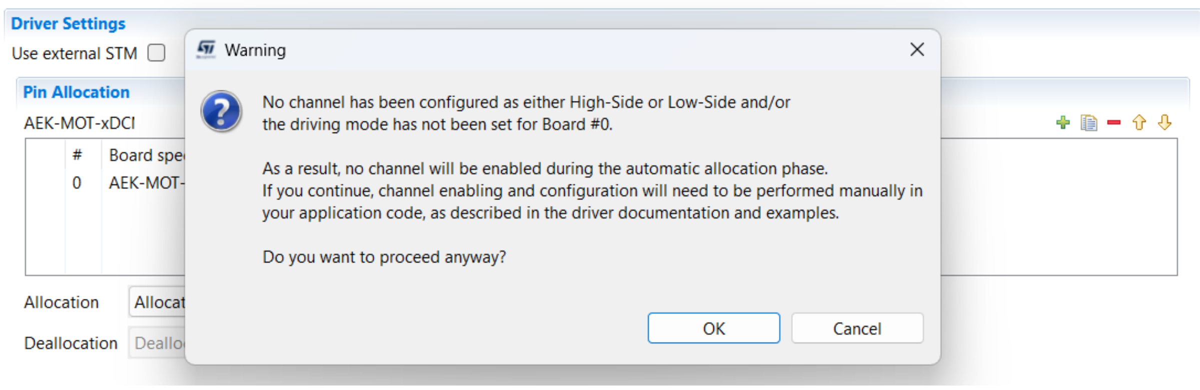


Figure 70. Allocation failed for wrong PWM frequency or duty cycle



If you do not set ”Side to enable” and ”Side driving mode” fields, no channel is active. As a result, when starting the allocation procedure, a "no channel enabled or configured" warning appears. Any required channel enabling and configuration must then be performed manually by the user in the application code.

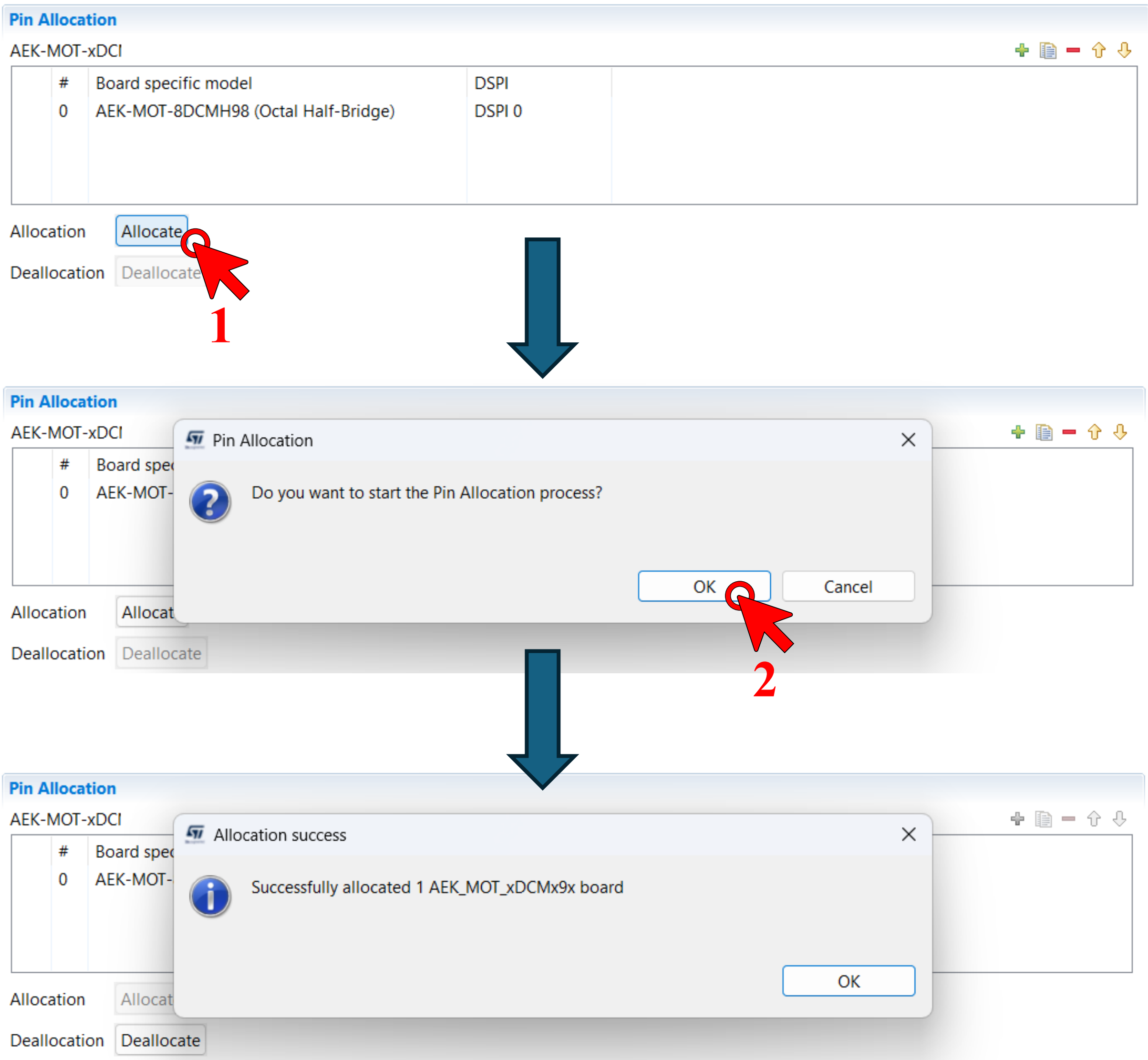
Figure 71. No channel allocation



If no error or warning occurs, you can start the allocation procedure. During allocation, several pop-up messages confirm the peripheral configuration. If the process is successfully completed, a final pop-up message confirms the successful allocation and displays the number of boards allocated.

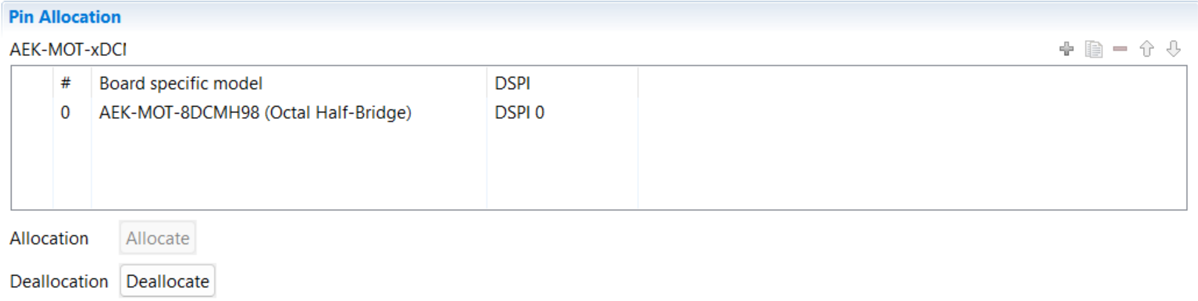
- **DSPI**: Four pins are allocated for MISO, MOSI, clock, and chip-select for each DSPI peripheral selected among the boards. If multiple boards share the same DSPI peripheral, the MISO, MOSI, and clock pins are shared, and one chip-select pin is allocated for each board sharing the peripheral. The Low-Level Drivers component configures all DSPI peripherals to be used.
- **STM**: If the “Use External STM” field is not selected, one STM channel is configured from those available in the Low-Level Drivers component. No pins are allocated for the STM peripheral.
- **eMIOS**: Three eMIOS pins are allocated for each board for PWM1, PWM2, and PWM3 functions, and configured at the specified frequencies.
- **GPIO**: One GPIO pin is always allocated for each board for the enable function.
- **EIRQ**: One EIRQ pin is allocated for each board for the DIAGN function.
- **ADC**: Three ADC pins are always allocated and configured for each board for the following functions:
  - VDH sensing
  - CSO1
  - CSO2
  - Additional ADC pins are allocated when “Enable load sensing” is selected in the load configuration to enable current sensing for specified channels.

Figure 72. Successful allocation



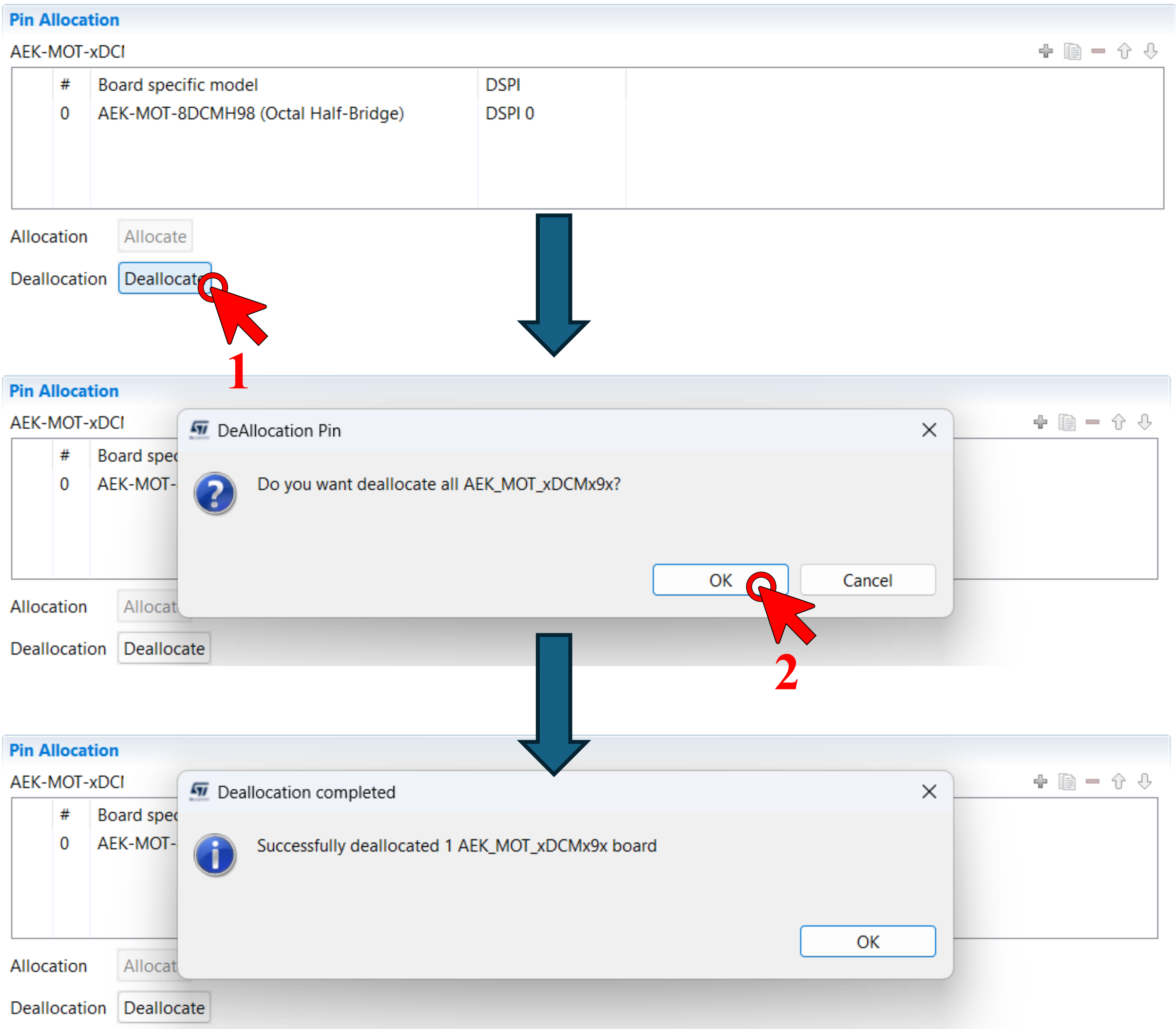
At this point, the allocation is complete. The list containing the different boards cannot be modified anymore, and each element is no longer accessible. The allocation button is disabled, while the deallocation button is enabled.

Figure 73. Deallocation button enabled



By clicking the deallocation button, the system releases each allocated resource and removes every configuration. Similarly, at the end of the operation, a pop-up appears to confirm successful completion and indicate the number of boards deallocated.

Figure 74. Successful deallocation



Consequently, after deleting all operations performed during allocation, the board list becomes active and editable again. The allocation button is active, while the deallocation button is inactive.

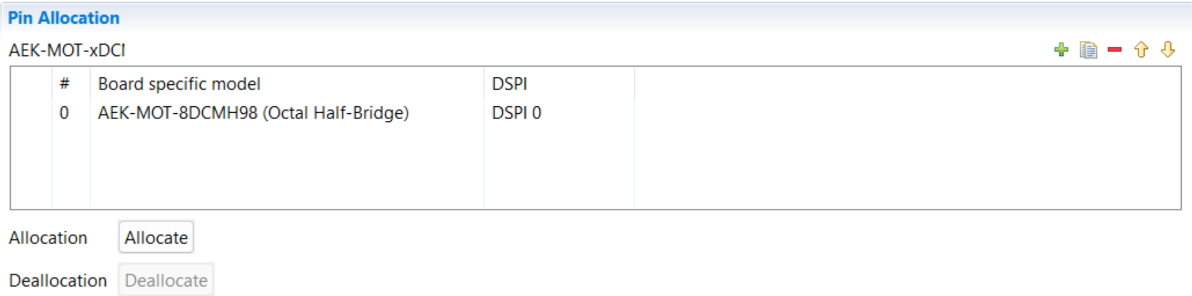


Figure 75. **Allocation button enabled**

2.2.2 Code generation

After allocation, generate the application code by using the designated button in the right section of the screen.

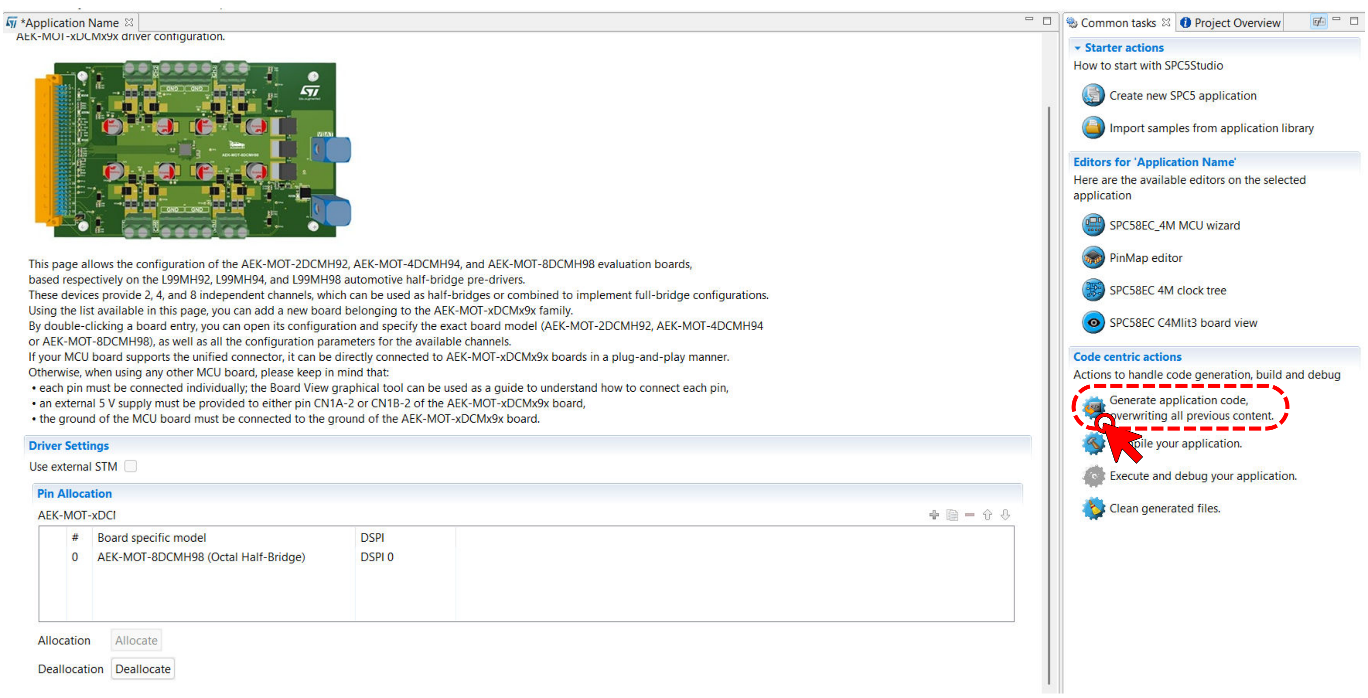
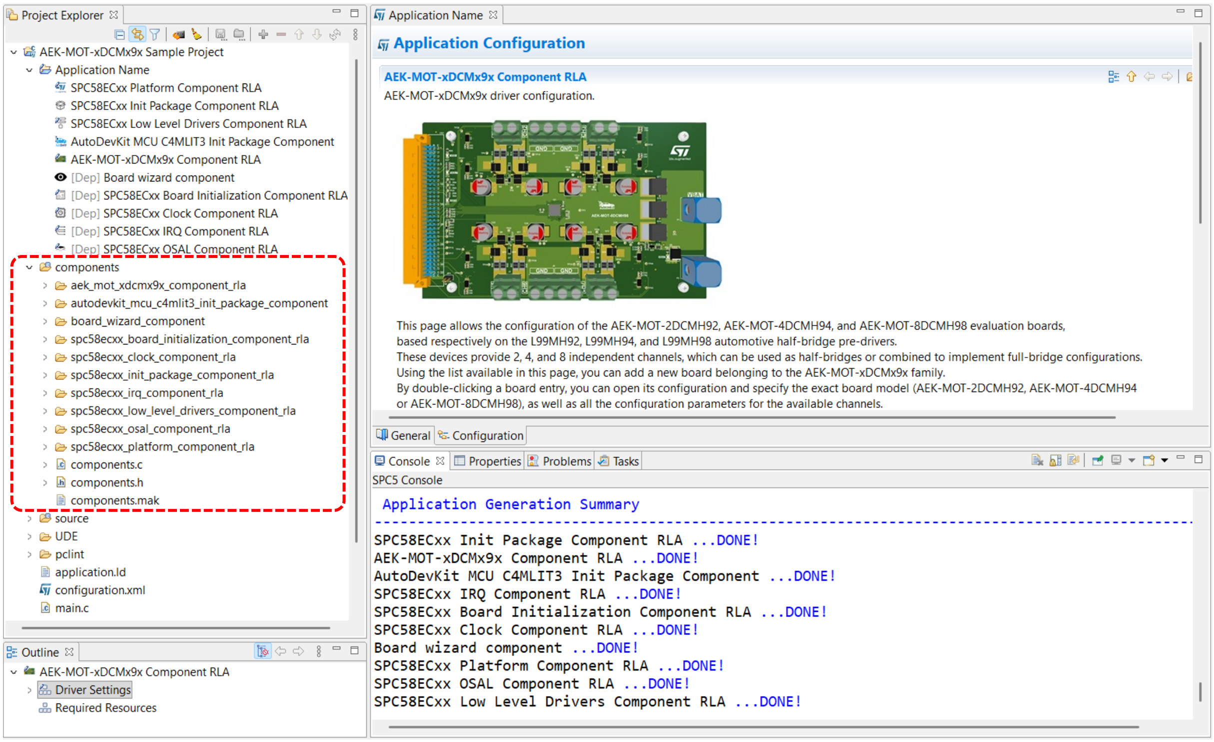


Figure 76. **Generate application code**

By clicking on "Generate application code", the tool generates all application code for every component in the project, using every configuration created. The code for each component is added to a folder named *Components*, which is visible in the left section of the project view.

Figure 77. Code created



2.2.3 Demo description

The available demos from AutoDevKit Studio release 2.8.1 are summarized in the table below:

Table 3. Available demos

Demo	MCU board	Load configuration	Current measurement	Measure output
AEK-MCU-C4MLIT3 - AEK-MOT-8DCMH98 HB and FB	AEK-MCU-C4M3	1 full bridge + 1 half bridge	Direct via shunts	On a serial terminal via UART
AEK-MCU-C4MLIT3 - AEK-MOT-4DCMH94 HB and FB	AEK-MCU-C4M3	1 full bridge + 1 half bridge	Direct via shunts	On a serial terminal via UART
AEK-MCU-C4MLIT3 - AEK-MOT-8DCMH98 FB Indirect Current Measurement	AEK-MCU-C4M3	1 full bridge	Indirect via diode + CSO	On a serial terminal via UART

These demos show how the L99MH9x can be used in practical motor-control scenarios, with particular focus on bridge actuation, PWM-based load driving, voltage and current acquisition, and serial monitoring.

The demos provide reference examples for:

- configuration and activation of L99MH9x outputs,
- actuation of loads in half-bridge and full-bridge configurations,
- duty-cycle variation through PWM control,
- monitoring of analog quantities such as supply voltage, CSO voltages, and load current,
- validation of both direct and indirect current measurement methods,
- integration with MCU boards supported by AutoDevKit Studio.

While the exact hardware setup and measurement strategy differ, the demos share the same software framework and a common control flow.

2.2.3.1 Demo software framework

In all demos, the application software is divided into two logical parts:

1. Initial configuration phase, executed once at startup.
2. Cyclic execution phase, implemented inside the infinite main loop.

Initial configuration phase

During the initial configuration phase, the application typically performs the following operations:

- *componentsInit()*
  Initializes all board peripherals and low-level software components generated by AutoDevKit Studio.
- *irqIsrEnable()*
  Enables interrupt handling.
- *L99MH9x_dev_initAll()*
  Initializes all L99MH9x devices used by the application.
- *L99MH9x_dev_powerOnAll()*
  Powers the devices on and applies the user-configured channel settings.

After device initialization, the application configures the channels used by the demo. Depending on the selected example, the software configures:

- one full-bridge load on channels CH1 and CH2,
- optionally one additional half-bridge load on CH3,
- the PWM source used for actuation, typically PWM1,
- per-channel output enable,
- and the global output enable through OUTE.

The main configuration functions used in the demos are:

- *L99MH9x_dev_setEN_PWMy()*
  Enables or disables the selected PWM input in the global configuration register.
- *L99MH9x_ch_setHB_MODE()*
  Sets the half-bridge operating mode of a specific channel.
- *L99MH9x_ch_setHB_PWM()*
  Associates the selected PWM input to the appropriate high-side or low-side MOSFET of the channel.
- *L99MH9x_ch_setOUT_ENABLE()*
  Enables a specific channel output.
- *L99MH9x_dev_setOUTE()*
  Enables global output actuation for the device.
- *L99MH9x_dev_pwm_start()*
  Starts the selected PWM with the specified duty cycle.

Common cyclic behavior

Once initialization is complete, all demos execute a cyclic sequence in which the PWM duty cycle is updated and measurements are refreshed.

The PWM duty cycle follows the sequence:

- 30%
- 60%
- 90%
- 60%
- 30%

Each operating point is maintained for approximately 2 seconds. Then, the application goes to the next step and the sequence is repeated indefinitely.

Depending on the demo, the software:

- reverses the direction of the full-bridge motor at the end of the sequence,
- acquires direct current values through shunts,
- acquires CSO voltages and supply voltage,
- estimates current indirectly from V_{DS} and temperature,
- transmits the measured values through a UART interface.

2.2.3.2 *Measurement functions used in the demos*

The following measurement-related functions are used, depending on the selected demo:

- *L99MH9x_saradc_measureCSO1Voltage()*
- *L99MH9x_saradc_measureCSO2Voltage()*
- *L99MH9x_saradc_measureVDHVoltage()*
- *L99MH9x_saradc_measureDev0Ch1LoadCurrent()*
- *L99MH9x_saradc_measureDev0Ch2LoadCurrent()*
- *L99MH9x_saradc_measureDev0Ch3LoadCurrent()*

The corresponding “get latest value” functions are then used to retrieve the converted values from the ADC software layer.

In the indirect current measurement demo, additional high-level functions are used to calculate the load current from temperature and V_{DS} measurements, such as:

- *L99MH9x_ch_getRds()*
- *L99MH9x_ch_measureHBSideVdsOnCSO1()*
- *L99MH9x_ch_measureHBSideCurrentIndirectlyOnCSO1()*

For further details about these functions and indirect current measurement workflow, refer also to Section 1.4.2.2.

2.2.3.3 *Watchdog handling*

During operation, the L99MH9x watchdog must be periodically served to avoid entering fail-safe mode.

In the demo framework, this task is handled automatically by a timer-driven callback. The callback periodically triggers the watchdog service routine, which sends the watchdog command through SPI and refreshes the timing reference used by the software. This ensures that the L99MH9x remains in normal operating condition throughout the demo execution.

2.2.3.3.1 **“AEK-MCU-C4MLIT3 - AEK-MOT-8DCMH98/AEK-MOT-4DCMH94 HB and FB” demos**

This demo shows:

- full-bridge and half-bridge actuation,
- direct current measurement through shunts,
- CSO-based voltage monitoring,
- serial reporting of the measured quantities.

The demo implements the same motor-control use case as the previous one but targets the AEK-MCU-C4M3 board stacked directly on the AEK-MOT-8DCMH98/AEK-MOT-4DCMH94 evaluation board through the unified connector.

Using this demo, you can:

- drive one full-bridge load on CH1 - CH2
- drive one half-bridge load on CH3
- implement direct current measurement through shunt resistors
- acquire VDH value
- monitor MOSFET V_{DS} through CSO1 and CSO2
- read the acquired values through UART via serial terminal

At each step of the PWM sequence, the application transmits a message containing:

- current step
- PWM duty cycle
- current on CH1
- current on CH2
- current on CH3
- VDH voltage
- CSO1 voltage
- CSO2 voltage

2.2.3.3.2 “AEK-MCU-C4MLIT3 - AEK-MOT-8DCMH98 FB Indirect Current Measurement” demo

This demo shows the complete software implementation of the indirect current measurement feature supported by the L99MH98, including:

- temperature estimation from the external diode
- temperature-dependent $R_{DS(on)}$ estimation
- VDS measurement through the CSO path
- current calculation without using an external shunt.

It targets the same AEK-MCU-C4M3 + AEK-MOT-8DCMH98 hardware combination but differs from the previous demos in both the selected load configuration and the current-sense strategy.

In this application:

- only one full-bridge load is driven, using channels CH1 and CH2
- no additional half-bridge load is configured
- current is not measured through a shunt resistor, but estimated indirectly by software

The current estimation flow is based on:

- acquisition of the external diode forward voltage
- estimation of diode temperature
- estimation of MOSFET temperature using a calibrated offset
- computation of MOSFET $R_{DS(on)}$ at the estimated temperature
- acquisition of MOSFET V_{DS} through CSO1
- computation of the actual current using the following formula: $I_{DS} = \frac{V_{DS}}{R_{DS(on)}(T)}$

At each PWM step, the application transmits through UART:

- current step,
- PWM duty cycle,
- estimated full-bridge current.

For further details about indirect current measurement workflow and related software functions, refer also to Section 1.4.2.2 and AN6309.

3 AEK-MOT-8DCMH98 schematic diagrams

Figure 78. AEK-MOT-8DCMH98 circuit schematic (1 of 4)

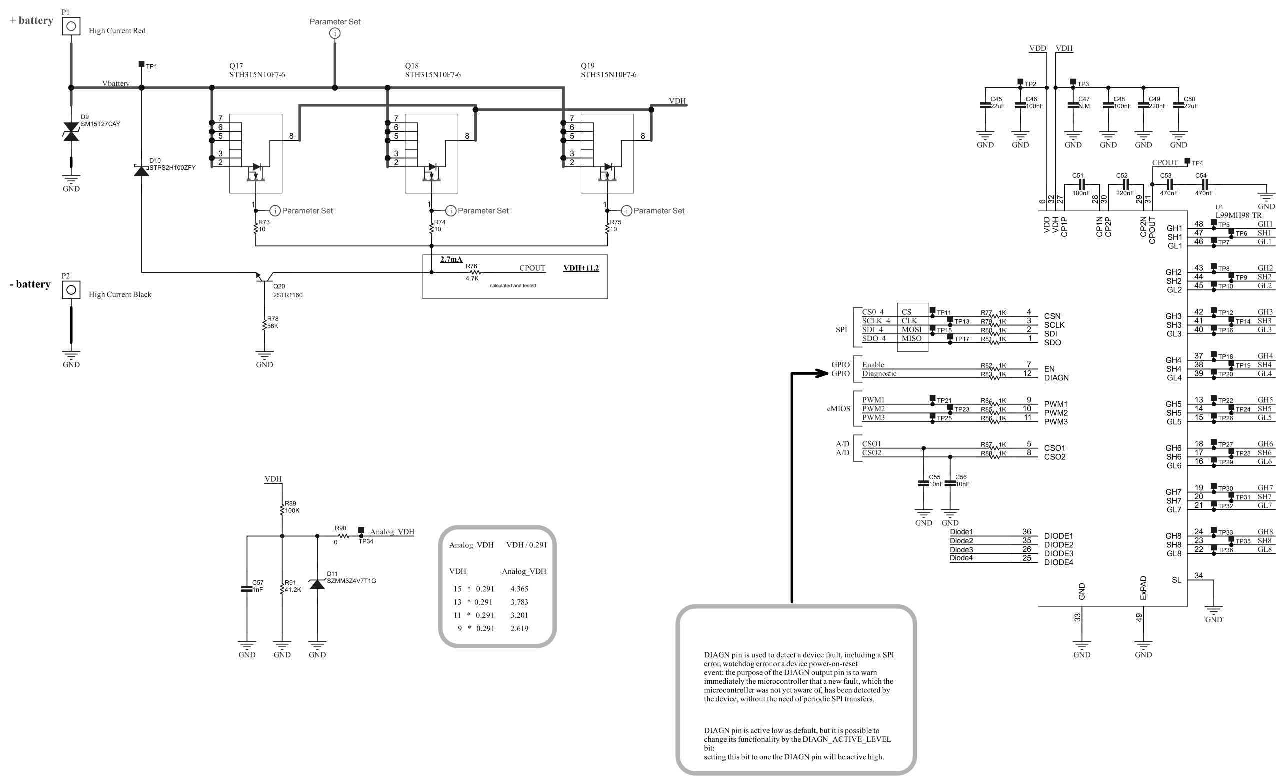
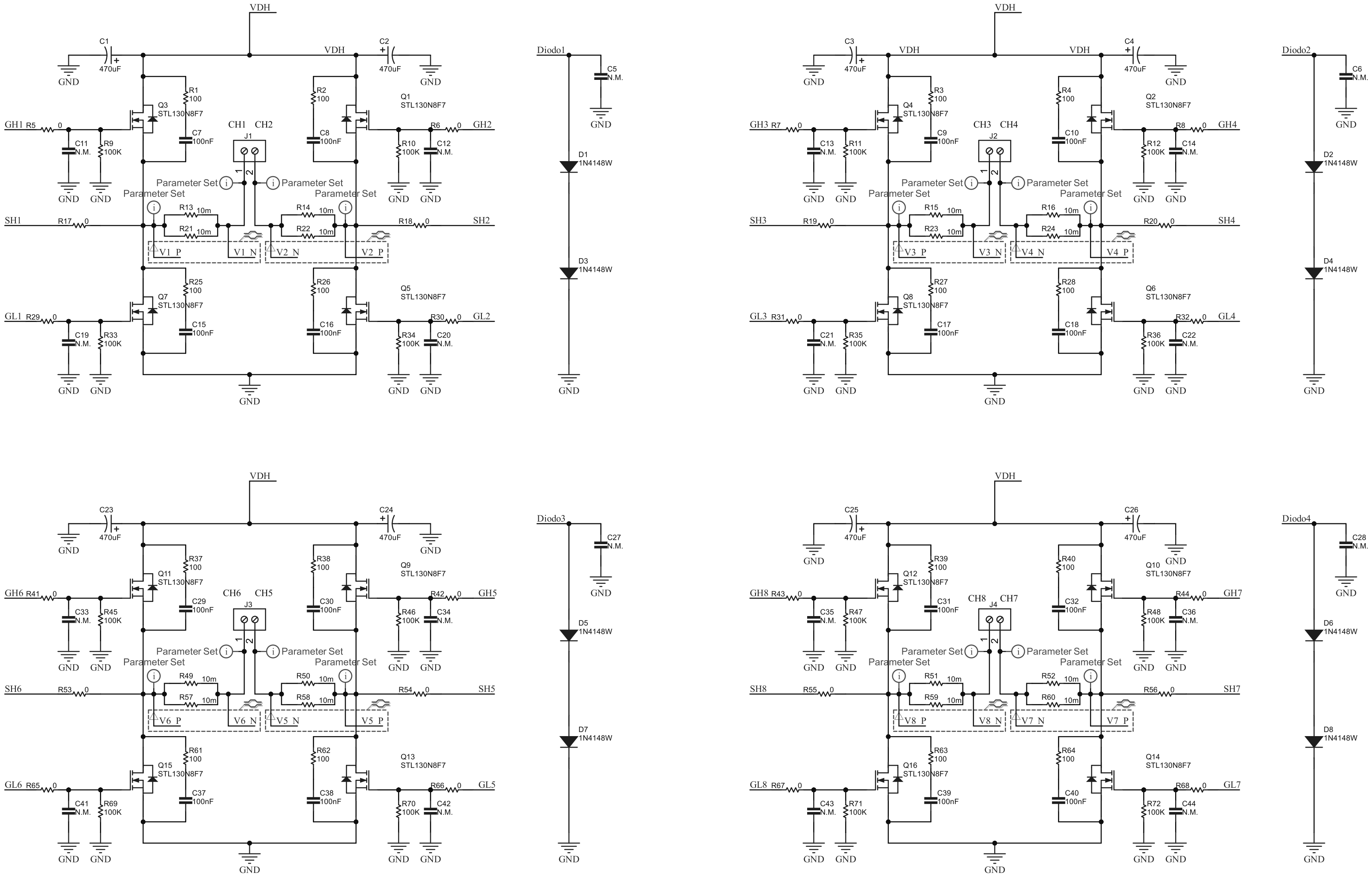
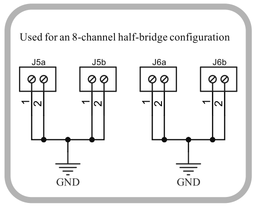


Figure 79. AEK-MOT-8DCMH98 circuit schematic (2 of 4)





Order code	V_{DS}	$R_{DS(on)}$ max.	I_D	P_{TOT}
STL130N8F7	80 V	3.6 mΩ	120 A	135 W

Figure 80. **AEK-MOT-8DCMH98 circuit schematic (3 of 4)**

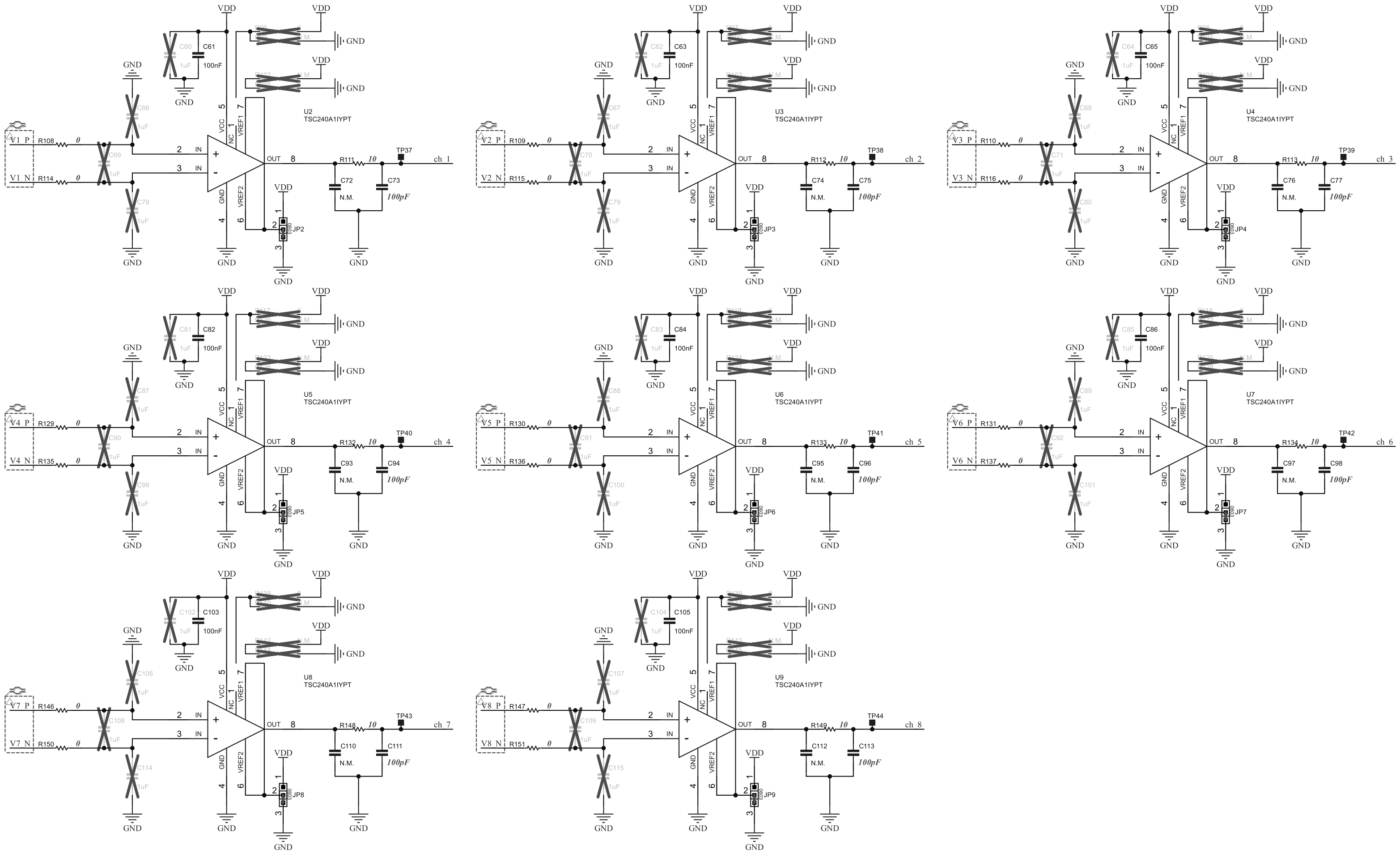
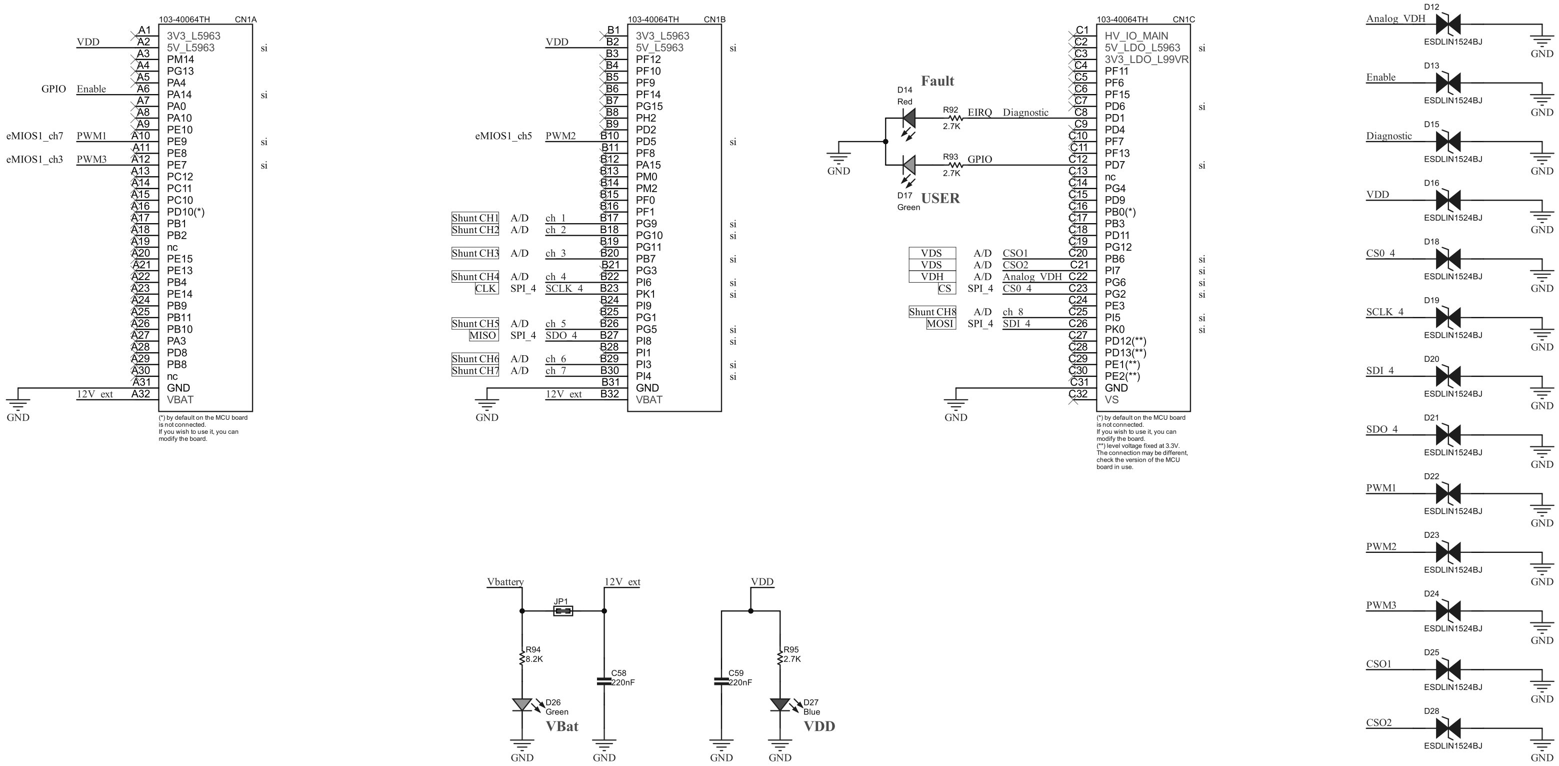


Figure 81. AEK-MOT-8DCMH98 circuit schematic (4 of 4)



4 AEK-MOT-8DCMH98 Bill of materials

Table 4. AEK-MOT-8DCMH98 bill of materials

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
1	8	C1, C2, C3, C4, C23, C24, C25, C26	470uF	Electrolytic Cap - 25V - 10x10.5	WE	865060457009
2	29	C5, C6, C11, C12, C13, C14, C19, C20, C21, C22, C27, C28, C33, C34, C35, C36, C41, C42, C43, C44, C47, C72, C74, C76, C93, C95, C97, C110, C112	N.M.	0603	N.A.	N.A.
3	27	C7, C8, C9, C10, C15, C16, C17, C18, C29, C30, C31, C32, C37, C38, C39, C40, C46, C48, C51, C61, C63, C65, C82, C84, C86, C103, C105	100nF	0603 - 50V - X7R Class II	WE	885012206095
4	2	C45, C50	22uF	1210 - 25V - X7R Class II	WE	885012209074
5	4	C49, C52, C58, C59	220nF	0603 - 50V - X7R Class II	WE	885012206125
6	2	C53, C54	470nF	0805 - 50V - X7R Class II	WE	885012207102
7	2	C55, C56	10nF	0603 - 50V - X7R Class II	WE	885012206089
8	1	C57	1nF	0603 - 50V - X7R Class II	WE	885012206083
9	8	C73, C75, C77, C94, C96, C98, C111, C113	100pF	0603 - 100V - X7R Class II	WE	885012206102
10	1	CN1	103-40064TH	DIN 41612 Male 90°, type C, Part No. 103-40064TH	EPT	103-40064TH
11	8	D1, D2, D3, D4, D5, D6, D7, D8	1N4148W	Silicon epitaxial planar diode	Vishay	1N4148W-HE3_A-08
12	1	D9	SM15T27CAY, SMC	SMC TVS - 27VDC - Bidirectional - 1500W	ST	SM15T27CAY
13	1	D10	STPS2H100ZFY, SOD123Flat	Automotive 100V, 2A Power Schottky Rectifier	ST	STPS2H100ZFY
14	1	D11	SZMM3Z4V7T1G	4.7V Zener Voltage Regulators, 300mW	Onsemi	SZMM3Z4V7T1G

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
15	13	D12, D13, D15, D16, D18, D19, D20, D21, D22, D23, D24, D25, D28	ESDLIN1524BJ, SOD323	Automotive Transil™, transient voltage suppressor (TVS) for LIN bus	ST	ESDLIN1524BJ
16	1	D14	Red	0805 - Led Red - 2V	WE	150080RS75000
17	2	D17, D26	Green	0805 - Led Green - 3.2V	WE	150080GS75000
18	1	D27	Blue	0805 - Led Blue - 3.2V	WE	150080BS75000
20	8	J1, J2, J3, J4, J5a, J5b, J6a, J6b	Con 2p 7.62_green	7.62mm - WR-TBL Series 2184 Horizontal Entry Modular w. Rising Cage Clamp	WE	691218410002
21	1	JP1	Jumper 2p Closed	2.54mm - Pin Header, THT, pitch 2.54mm, Single Row, Vertical, 2p, Closed	WE	61300211121
22	8	JP2, JP3, JP4, JP5, JP6, JP7, JP8, JP9	0	0805_Jumper 3p Closed SMD	Vishay	RCC06030000Z0EA
23	1	P1		WP-PLUG REDCUBE Direct Plug Terminal, 14.8x14.8x18.1 mm, Red, 120A	WE	7464000
24	1	P2		WP-PLUG REDCUBE Direct Plug Terminal, 14.8x14.8x18.1 mm, Black, 120A	WE	7464100
25	16	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13, Q14, Q15, Q16	STL130N8F7, PowerFLAT 5x6	Automotive-grade N-channel 80 V, 3.6 mΩ typ., 120 A STripFET F7 Power MOSFET in a PowerFLAT 5x6 package	ST	STL130N8F7
26	3	Q17, Q18, Q19	STH315N10F7-6, H2PAK-6	MOSFET LGS LV MOSFET	ST	STH315N10F7-6
27	1	Q20	2STR1160, SOT-23	NPN Bipolar Transistor 60V, 1A	ST	2STR1160
28	16	R1, R2, R3, R4, R25, R26, R27, R28, R37, R38, R39, R40, R61, R62, R63, R64	100	0603 - ±1% - 0.125W	Panasonic	ERJH3EF1000V

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
29	25	R5, R6, R7, R8, R17, R18, R19, R20, R29, R30, R31, R32, R41, R42, R43, R44, R53, R54, R55, R56, R65, R66, R67, R68, R90	0	0603 - ±1% - 0.1W	Panasonic	ERJ3GEY0R00V
30	17	R9, R10, R11, R12, R33, R34, R35, R36, R45, R46, R47, R48, R69, R70, R71, R72, R89	100K	0603 - ±1% - 0.2W	Panasonic	ERJP03F1003V
31	16	R13, R14, R15, R16, R21, R22, R23, R24, R49, R50, R51, R52, R57, R58, R59, R60	10m	2512 - ±1% - 5W	SEI Stackpole	CSSU2512FT10L0
32	11	R73, R74, R75, R111, R112, R113, R132, R133, R134, R148, R149	10	0603 - ±1% - 0.25W	Panasonic	ERJPA3F10R0V
33	1	R76	4.7K	0603 - ±1% - 0.25W	Panasonic	ERJPA3F4701V
34	11	R77, R79, R80, R81, R82, R83, R84, R85, R86, R87, R88	1K	0603 - ±1% - 0.25W	Panasonic	ERJPA3F1001V
35	1	R78	56K	0603 - ±1% - 0.25W	Panasonic	ERJPA3F5602V
36	1	R91	41.2K	0805 - ±0.1% - 0.1W	Panasonic	ERA3ARB4122V
37	3	R92, R93, R95	2.7K	0603 - ±1% - 0.1W	Vishay	MCT06030C2701FP500
38	1	R94	8.2K	0603 - ±1% - 0.1W	Panasonic	ERJ-3EKF8201V
39	16	R108, R109, R110, R114, R115, R116, R129, R130, R131, R135, R136, R137, R146, R147, R150, R151	0	0603 - jumper - 1A	Panasonic	ERJH3G0R00V
40	1	U1	L99MH98-TR, VFQFN 7X7X0.9 48L WETT. FLANKS	L99MH98 is an integrated octal half-bridge pre-driver dedicated to control up to sixteen N-channel MOSFETs	ST	L99MH98-TR

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
41	8	U2, U3, U4, U5, U6, U7, U8, U9	TSC240A1IYPT, TSSOP-8L	High-side and low-side bidirectional zero-drift current sense amplifier with enhanced PWM rejection, G=20	ST	TSC240A1IYPT
42	1	for blister	60900213421	WR-PHD 2.54 mm Multi-Jumper Jumper with Test Point	WE	60900213421
43	4	for blister	97790603211	WA-SCRW Pan Head Screw w. cross slot M3	WE	97790603211
44	4	for blister	970150365	WA-SPAII Plastic Spacer Stud, metric, internal/ internal	WE	970150365
45	2	for blister	74640016	WP-PLUG REDCUBE Cable Connector for Direct PLUG Terminal	WE	74640016

5 AEK-MOT-8DCMH98 Board versions

Table 5. AEK-MOT-8DCMH98 versions

Finished good	Schematic diagrams	Bill of materials
AEK$MOT-8DCMH98A (1)	AEK$MOT-8DCMH98A schematic diagrams	AEK$MOT-8DCMH98A bill of materials

1. This code identifies the AEK-MOT-8DCMH98 evaluation board first version.

6 AEK-MOT-8DCMH98 regulatory compliance information

Notice for US Federal Communication Commission (FCC)

For evaluation only; not FCC approved for resale

FCC NOTICE - This kit is designed to allow:

(1) Product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and

(2) Software developers to write software applications for use with the end product.

This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter 3.1.2.

Notice for Innovation, Science and Economic Development Canada (ISED)

For evaluation purposes only. This kit generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to Industry Canada (IC) rules.

À des fins d'évaluation uniquement. Ce kit génère, utilise et peut émettre de l'énergie radiofréquence et n'a pas été testé pour sa conformité aux limites des appareils informatiques conformément aux règles d'Industrie Canada (IC).

Notice for the European Union

This device is in conformity with the essential requirements of the Directive 2014/30/EU (EMC) and of the Directive 2011/65/EU (RoHS II), including subsequent revisions and additions, as well as amended by the Delegated Directive 2015/863/EU (RoHS III). Compliance to EMC standards in Class A (industrial intended use).

Notice for the United Kingdom

This device is in conformity with the relevant provisions of the following EU legislation recognized by the United Kingdom:

- Electromagnetic Compatibility Regulations 2016 (S.I. 2016/1091) implementing Directive 2014/30/EU (EMC). Compliance to EMC standards in Class A (industrial intended use).
- The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012 (RoHS) (S.I. 2012/3032) implementing Directive 2011/65/EU (RoHS II), including subsequent revisions and additions, as well as amended by the Delegated Directive 2015/863/EU (RoHS III).

7 AEK-MOT-4DCMH94 schematic diagrams

Figure 82. AEK-MOT-4DCMH94 circuit schematic (1 of 4)

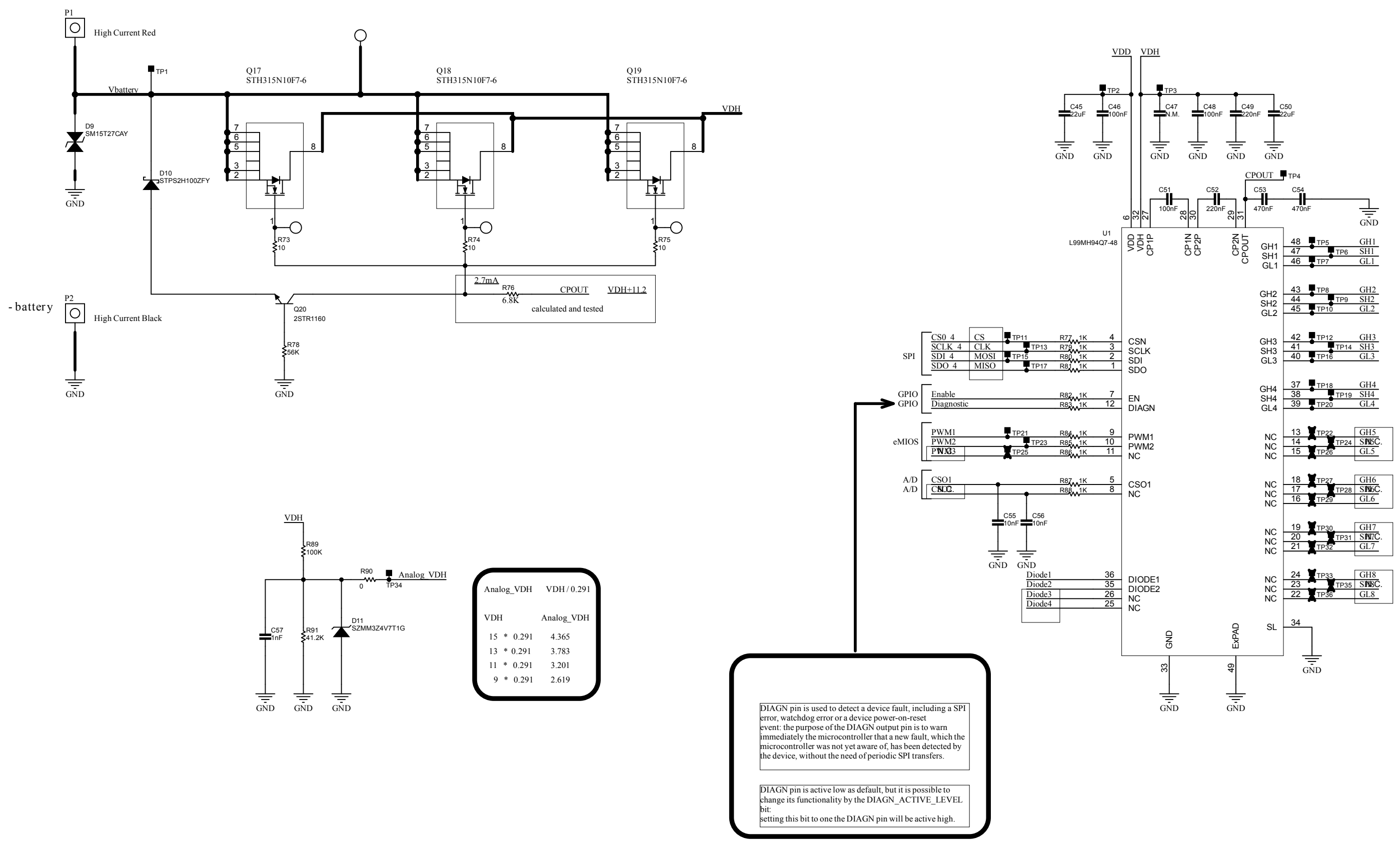
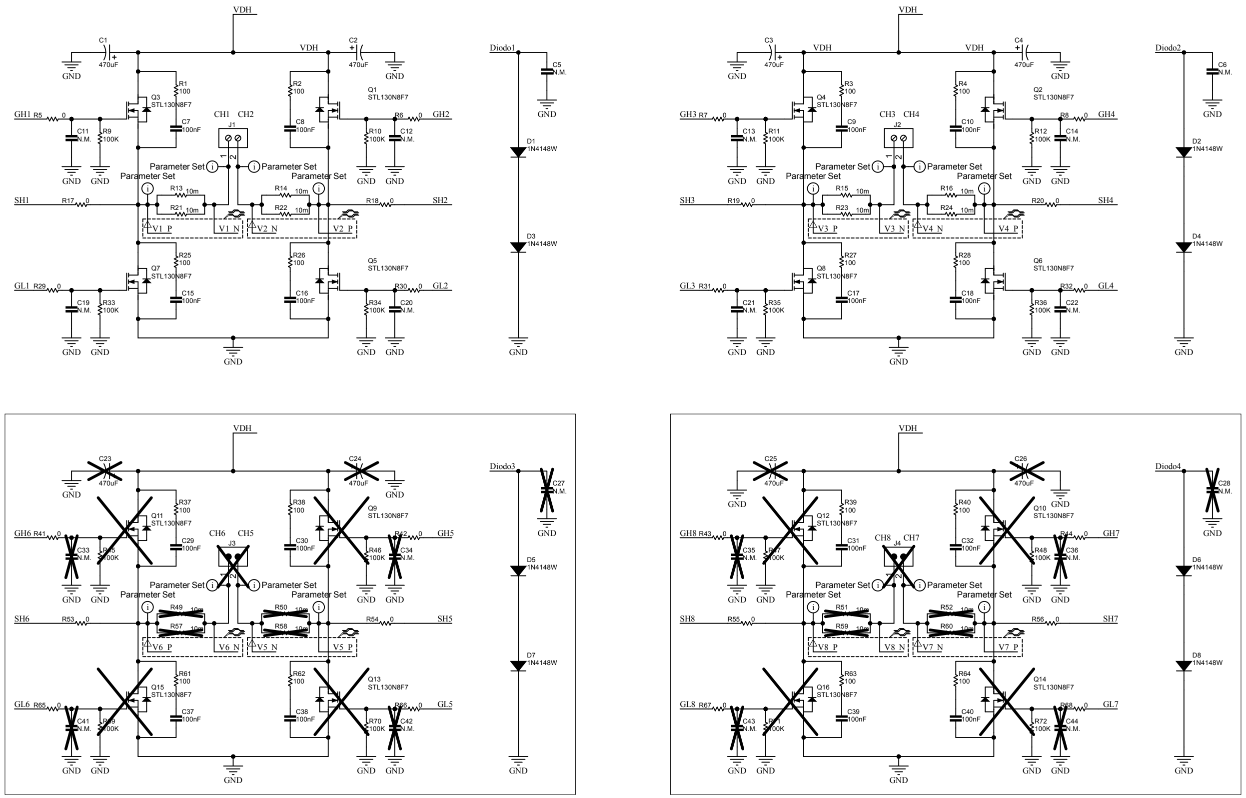
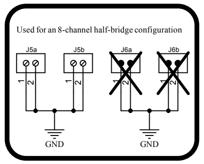


Figure 83. AEK-MOT-4DCMH94 circuit schematic (2 of 4)





Order code	V_{DS}	$R_{DS(on)}$ max.	I_D	P_{TOT}
STL130N8F7	80 V	3.6 mΩ	120 A	135 W

Figure 84. AEK-MOT-4DCMH94 circuit schematic (3 of 4)

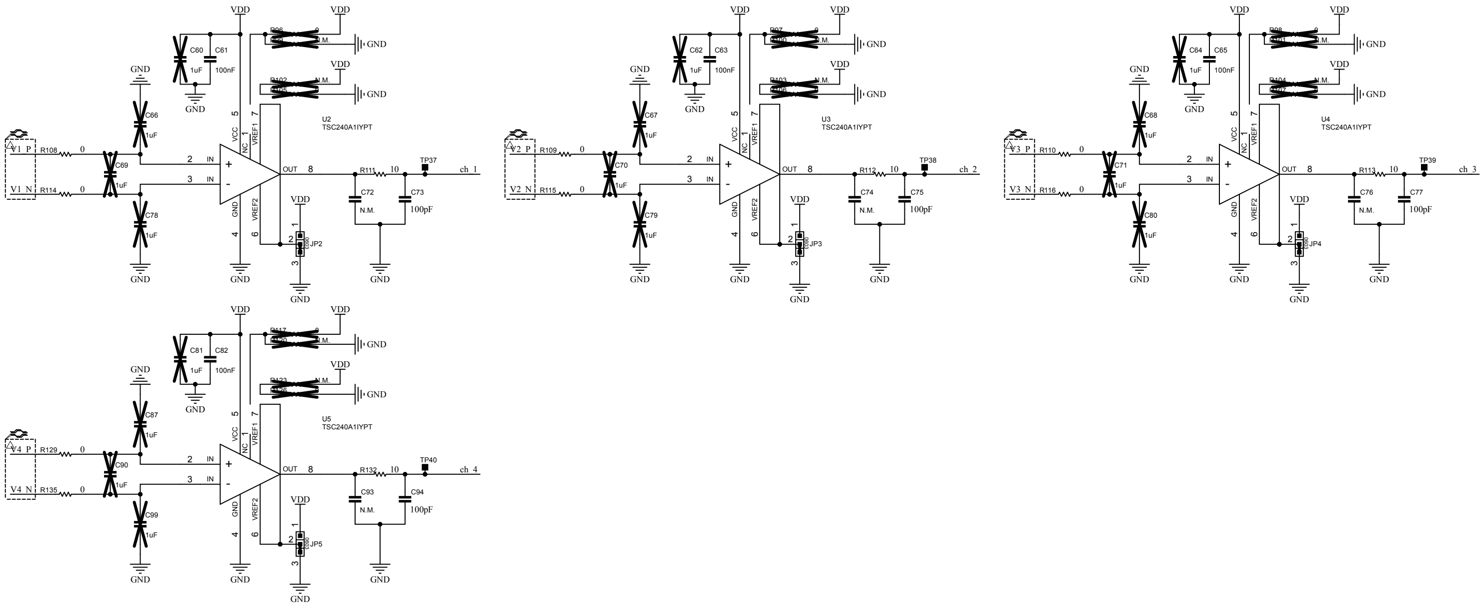
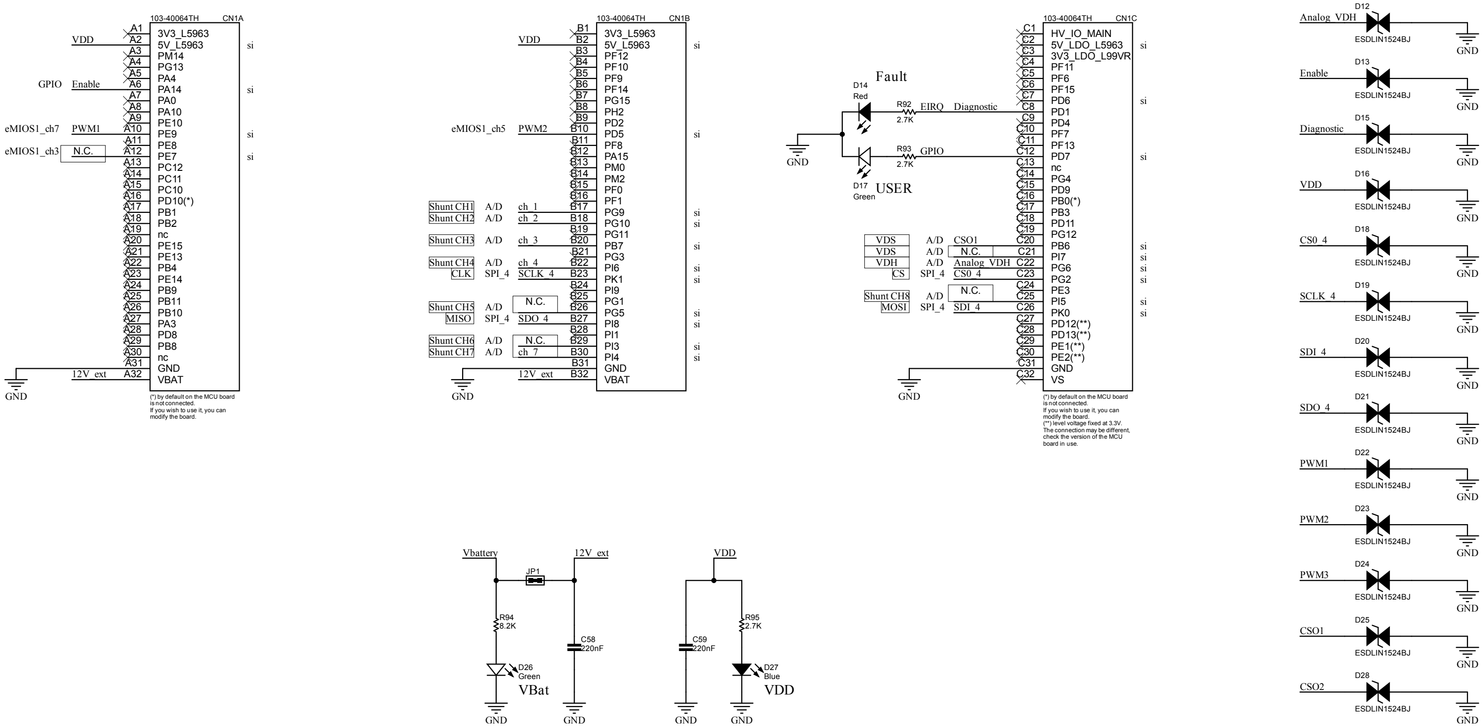


Figure 85. **AEK-MOT-4DCMH94 circuit schematic (4 of 4)**



8 AEK-MOT-4DCMH94 Bill of materials

Table 6. **AEK-MOT-4DCMH94 bill of materials**

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
1	4	C1, C2, C3, C4	470uF	Electrolytic Cap - 25V - 10x10.5	WE	865060457009
2	15	C5, C6, C11, C12, C13, C14, C19, C20, C21, C22, C47, C72, C74, C76, C93	N.M.	0603	N.A.	N.A.
3	27	C7, C8, C9, C10, C15, C16, C17, C18, C29, C30, C31, C32, C37, C38, C39, C40, C46, C48, C51, C61, C63, C65, C82, C84, C86, C103, C105	100nF	0603 - 50V - X7R Class II	WE	885012206095
4	2	C45, C50	22uF	1210 - 25V - X7R Class II	WE	885012209074
5	4	C49, C52, C58, C59	220nF	0603 - 50V - X7R Class II	WE	885012206125
6	2	C53, C54	470nF	0805 - 50V - X7R Class II	WE	885012207102
7	2	C55, C56	10nF	0603 - 50V - X7R Class II	WE	885012206089
8	1	C57	1nF	0603 - 50V - X7R Class II	WE	885012206083
9	4	C73, C75, C77, C94	100pF	0603 - 100V - X7R Class II	WE	885012206102
10	1	CN1	103-40064TH	DIN 41612 Male 90°, type C, Part No. 103-40064TH	EPT	103-40064TH
11	8	D1, D2, D3, D4, D5, D6, D7, D8	1N4148W	Silicon epitaxial planar diode	Vishay	1N4148W-HE3_A-08
12	1	D9	SM15T27CAY, SMC - NP	SMC TVS - 27VDC - Bidirectional - 1500W	ST	SM15T27CAY
13	1	D10	STPS2H100ZFY, SOD123 FLAT	Automotive 100V, 2A Power Schottky Rectifier	ST	STPS2H100ZFY
14	1	D11	SZMM3Z4V7T1G	4.7V Zener Voltage Regulators, 300mW	Onsemi	SZMM3Z4V7T1G
15	13	D12, D13, D15, D16, D18, D19, D20, D21, D22, D23, D24, D25, D28	ESDLIN1524BJ, SOD 323	Automotive Transil™, transient voltage suppressor (TVS) for LIN bus	ST	ESDLIN1524BJ
16	1	D14	Red	0805 - Led Red - 2V	WE	150080RS75000
17	2	D17, D26	Green	0805 - Led Green - 3.2V	WE	150080GS75000
18	1	D27	Blue	0805 - Led Blue - 3.2V	WE	150080BS75000

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
19	4	J1, J2, J5a, J5b	Con 2p 7.62_green	7.62mm - WR-TBL Series 2184 Horizontal Entry Modular w. Rising Cage Clamp	WE	691218410002
20	1	JP1	Jumper 2p Closed	2.54mm - Pin Header, THT, pitch 2.54mm, Single Row, Vertical, 2p, Closed	WE	61300211121
21	8	JP2, JP3, JP4, JP5, JP6, JP7, JP8, JP9	0	0805_Jumper 3p Closed SMD	Vishay	RCC06030000Z0EA
22	1	P1		WP-PLUG REDCUBE Direct Plug Terminal, 14.8x14.8x18.1mm, Red, 120A	WE	7464000
23	1	P2		WP-PLUG REDCUBE Direct Plug Terminal, 14.8x14.8x18.1mm, Black, 120A	WE	7464100
24	8	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8	STL130N8F7, 'PowerFLAT 5x6_WF type C	Automotive-grade N-channel 80 V, 3.6 mΩ typ., 120 A STripFET F7 Power MOSFET in a PowerFLAT 5x6 package	ST	STL130N8F7
25	3	Q17, Q18, Q19	STH315N10F7-6, H2PAK-6	MOSFET LGS LV MOSFET	ST	STH315N10F7-6
26	1	Q20	2STR1160, SOT-23	NPN Bipolar Transistor 60V, 1A	ST	2STR1160
27	16	R1, R2, R3, R4, R25, R26, R27, R28, R37, R38, R39, R40, R61, R62, R63, R64	100	0603 - ±1% - 0.125W	Panasonic	ERJH3EF1000V
28	25	R5, R6, R7, R8, R17, R18, R19, R20, R29, R30, R31, R32, R41, R42, R43, R44, R53, R54, R55, R56, R65, R66, R67, R68, R90	0	0603 - ±1% - 0.1W	Panasonic	ERJ3GEY0R00V
29	17	R9, R10, R11, R12, R33, R34, R35, R36, R45, R46, R47, R48, R69, R70, R71, R72, R89	100K	0603 - ±1% - 0.2W	Panasonic	ERJP03F1003V
30	8	R13, R14, R15, R16, R21, R22, R23, R24	10m	2512 - ±1% - 5W	SEI Stackpole	CSSU2512FT10L0
31	7	R73, R74, R75, R111, R112, R113, R132	10	0603 - ±1% - 0.25W	Panasonic	ERJPA3F10R0V
32	1	R76	6.8K	0603 - ±1% - 0.25W	Panasonic	ERJH3EF6801V

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
33	11	R77, R79, R80, R81, R82, R83, R84, R85, R86, R87, R88	1K	0603 - ±1% - 0.25W	Panasonic	ERJPA3F1001V
34	1	R78	56K	0603 - ±1% - 0.25W	Panasonic	ERJPA3F5602V
35	1	R91	41.2K	0805 - ±0.1% - 0.1W	Panasonic	ERA3ARB4122V
36	3	R92, R93, R95	2.7K	0603 - ±1% - 0.1W	Vishay	MCT06030C2701FP500
37	1	R94	8.2K	0603 - ±1% - 0.1W	Panasonic	ERJ-3EKF8201V
38	8	R108, R109, R110, R114, R115, R116, R129, R135	0	0603 - jumper - 1A	Panasonic	ERJH3G0R00V
39	1	U1	'L99MH94Q7-TR, VFQFN48L	The L99MH94 integrate respectively a quad half-bridge pre-driver dedicated to control up to eight N-channel MOSFETs.	ST	L99MH94Q7-TR
40	4	U2, U3, U4, U5	TSC240A1IYPT, TSSOP8	High-side and low-side bidirectional zero-drift current sense amplifier with enhanced PWM rejection, G=20	ST	TSC240A1IYPT
41	1	for blister	60900213421	WR-PHD 2.54 mm Multi-Jumper Jumper with Test Point	WE	60900213421
42	4	for blister	97790603211	WA-SCRW Pan Head Screw w. cross slot M3	WE	97790603211
43	4	for blister	970150365	WA-SPAII Plastic Spacer Stud, metric, internal/ internal	WE	970150365
44	2	for blister	74640016	WP-PLUG REDCUBE Cable Connector for Direct PLUG Terminal	WE	74640016

9 AEK-MOT-4DCMH94 Board versions

Table 7. AEK-MOT-4DCMH94 versions

Finished good	Schematic diagrams	Bill of materials
AEK$MOT-4DCMH94A (1)	AEK$MOT-4DCMH94A schematic diagrams	AEK$MOT-4DCMH94A bill of materials

1. *This code identifies the AEK-MOT-4DCMH94 evaluation board first version.*

10 AEK-MOT-4DCMH94 regulatory compliance information

Notice for US Federal Communication Commission (FCC)

For evaluation only; not FCC approved for resale

FCC NOTICE - This kit is designed to allow:

(1) Product developers to evaluate electronic components, circuitry, or software associated with the kit to determine

whether to incorporate such items in a finished product and

(2) Software developers to write software applications for use with the end product.

This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter 3.1.2.

Notice for Innovation, Science and Economic Development Canada (ISED)

For evaluation purposes only. This kit generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to Industry Canada (IC) rules.

À des fins d'évaluation uniquement. Ce kit génère, utilise et peut émettre de l'énergie radiofréquence et n'a pas été testé pour sa conformité aux limites des appareils informatiques conformément aux règles d'Industrie Canada (IC).

Notice for the European Union

This device is in conformity with the essential requirements of the Directive 2014/30/EU (EMC) and of the Directive 2011/65/EU (RoHS II), including subsequent revisions and additions, as well as amended by the Delegated Directive 2015/863/EU (RoHS III).

Notice for the United Kingdom

This device is in conformity with the relevant provisions of the following EU legislation recognized by the United Kingdom:

• Electromagnetic Compatibility Regulations 2016 (S.I. 2016/1091) implementing Directive 2014/30/EU (EMC)

• The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012 (RoHS) (S.I. 2012/3032) implementing Directive 2011/65/EU (RoHS II), including subsequent revisions and additions, as well as amended by the Delegated Directive 2015/863/EU (RoHS III).

Revision history

Table 8. **Document revision history**

Date	Revision	Changes
27-Apr-2026	1	Initial release.
10-Jul-2026	2	Updated title in cover page. Added references to the AEK-MOT-4DCMH94 evaluation board.

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