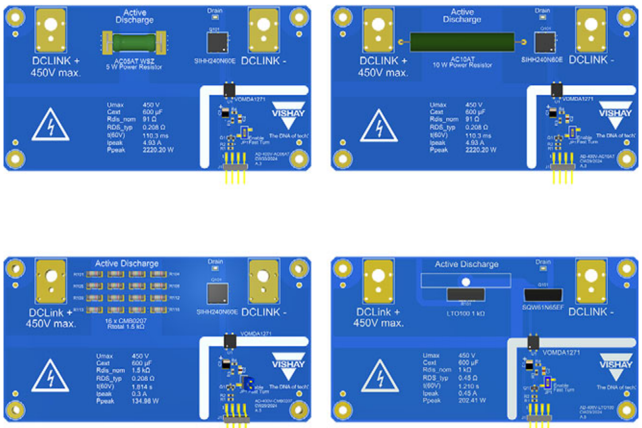
Reference Design
Active Discharge Circuit for 400 V Systems
Based on AC05AT, AC10AT, CMB0207, or LTO100 Resistors



FEATURES

- High pulse load surface-mounted wirewound resistors, carbon film MELF resistors, and thick film technology resistors
- Low part count isolated gate drive circuit without the need for an external power supply

KEY COMPONENTS

- AC05AT wirewound resistor
- LTO 100 power resistor, thick film technology
- CMB0207 high pulse load carbon film MELF resistors
- SiHH240N60E MOSFET
- VOMDA1271 photovoltaic gate driver

LINKS TO ADDITIONAL RESOURCES

- Active Discharge of 400 V DC-Link

DESCRIPTION

Active discharge is a known method of discharging the stored energy in a capacitor (or any other energy storing element) in a controlled manner in which the system voltage can reach to a safe value within a certain amount of time. In automotives, this time duration is defined by the car manufacturer according to legal requirements. For example, in automotive applications, the safe voltage is defined as 60 V, and the DC bus voltage must reach this value in less than 5 s after the crash. This is defined by United Nations regulation No. 94 of the Economic Commission for Europe of the United Nations. However, some OEMs prefer more restrictive discharge timing. Therefore, in this application we choose to set the discharge time at less than 2 s.

This reference design follows the design steps required to discharge a DC-Link bus voltage of 450 V to 60 V in less than 2 s for a 600 μF DC-Link capacitor. It is also required that the circuitry is able to repeat the discharge process three times within 15 s. Customers may follow the same steps to apply this design procedure to any other specific requirements.

Different resistor technologies within different design variants (four variants in total) are explored to give the customer a wide range of choices that match different kinds of applications.

1. SYSTEM BLOCK DIAGRAM

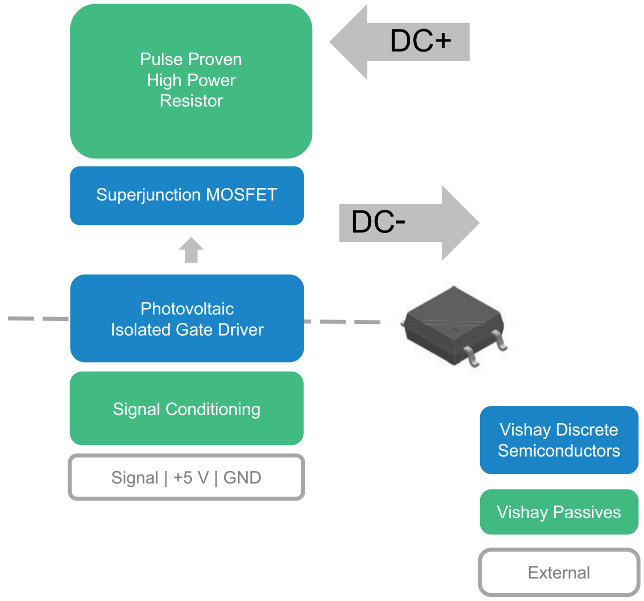


Fig. 1 - System Block Diagram

2. SYSTEM DESCRIPTION

The active discharge circuit comprises a few main components that work together to perform the required function: the gate driver, MOSFET, and discharge (bleeding) resistance. Sizing and selection of each one of these components are explained in the following subsections.

2.1. Gate Driver

The gate driver has to provide the required isolation between the control and power sections, and provide the required voltage and pulse current to turn the MOSFET to the saturation region. In this design, an automotive-qualified MOSFET driver (VOMDA1271) from Vishay is selected. The big advantage of the VOMDA1271 is its ability to obtain all the required energy to drive its internal circuitry from the infrared emitter on the low voltage, primary side of the isolation barrier. No power supply is needed to provide V_{CC}. The VOMDA1271 also features a turn-off circuit to achieve a fast turn-off of the MOSFET.

TABLE 1 - VOMDA1271 ELECTRICAL CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
LED forward voltage	I_F = 10 mA	V_F	1.3	1.4	1.5	V
Open circuit voltage	I_F = 5 mA	V_{OC}	-	8.2	-	V
	I_F = 10 mA	V_{OC}	6.5	8.5	-	V
	I_F = 20 mA	V_{OC}	-	8.8	-	V

From Table 1, in order to get an 8.5 V open circuit voltage (V_{OC}) to drive the MOSFET, a 10 mA forward current (I_F) is needed. In this application, the primary side power supply is selected to be 5 V.

In the forward operation of the primary side at 10 mA (I_F), the LED forward voltage may reach a typical value of 1.4 V at T_{amb} = 25 °C. To calculate the required resistance (R_3) to achieve the required forward current, and neglecting the $R_{DS(on)}$ of the small signal MOSFET, the following equation will apply:

$$R_3 = \frac{V_S - V_F}{I_F} = \frac{5\text{ V} - 1.4\text{ V}}{10\text{ mA}} \sim 360\ \Omega$$

For more details, the user may refer to the gate driver datasheet and / or application note listed under [3].

2.2. MOSFET

A 650 V MOSFET (SiHH240N60E) is selected to control the discharging time in this application. By turning on this MOSFET in saturation mode, the DC-Link capacitor's energy will be dissipated in the discharge resistance. This MOSFET should be able to withstand the amount of current passing through during the discharging time. It is also important that the MOSFET be able to dissipate the internal energy without crossing the maximum junction temperature.

For more details, customers may refer to the MOSFET datasheet shown in [4].

2.3. Discharge Resistance

Different variants of the discharge resistance are presented in this reference design.

- Vishay power wirewound resistors (variant 1 and variant 2) are rated for short term power and voltage levels (5 s or less), and can actually withstand much higher levels for brief periods of time (less than the cross-over point)[1]. In this application, two wirewound resistors (AC05AT and AC10AT) are chosen to be the discharge resistance with a value of 91 Ω
- Vishay carbon film MELF resistors (variant 3) benefit from advanced pulse load capability. In this application, 16 CMB0207 resistors are chosen with a value of 1.5 kΩ
- Vishay power resistors, thick film technology (variant 4), benefit from being a direct-mounted ceramic on the heatsink. In this application, the LTO100 is chosen with a value of 1 kΩ

The known equation for the voltage across a resistor in an RC circuit is:

$$v(t) = v_0 e^{-\left(\frac{t}{RC}\right)} \quad (1)$$

Where:

- v(t) is the voltage across the capacitor at time t
- v_0 is the initial voltage across the capacitor
- R is the resistance of the discharge resistor
- C is the capacitance of the DC-Link capacitor

This equation can be re-arranged to get the required resistance to discharge the capacitor within a certain duration.

In this application, different resistance types and values are presented to cover a wide range of applications.

Considering the system parameters in Table 2 and the chosen resistor values shown in Table 3, Fig. 2 shows different discharge times for all variants, confirming that all resistors are getting below 60 V in less than 2 s.

TABLE 2 - SYSTEM PARAMETERS

PARAMETER	VALUE
C	600 µF
V	650 V
Discharge to 60 V in	< 2 s
Ambient temperature	25 °C and 90 °C

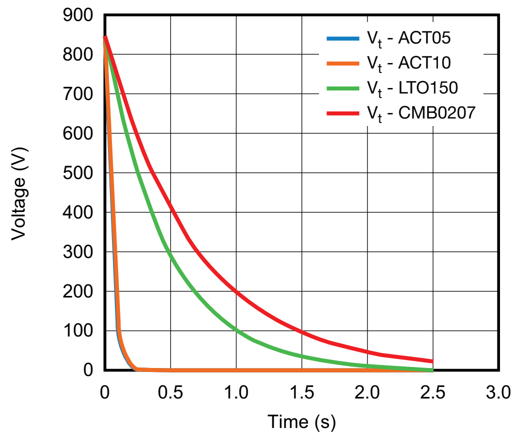


Fig. 2 - Different Discharging Times

2.4. Thermal Capacity Evaluation

While dissipating the energy through the discharge resistance, it is important that the temperature of the discharge resistance stays within the permissible limit. Also, as the power MOSFET is in series with the discharge resistance, it is important to validate the temperature rise of the power MOSFET and make sure it is within the accepted limit.

Temperature rise can be evaluated using a simplified thermal model explained in [2], which uses the internal thermal resistance of the component, which is normally given within the datasheet.

$$T_{resistance} = T_{amb} + dT \quad (2)$$

Where:

- $T_{resistance}$ is the rising temperature
- T_{amb} is the ambient temperature
- dT is the temperature rise due to the energy dissipation. This can be calculated by applying P_{loss} x R_{th}, or from the graphs provided in the datasheet
- P_{loss} is the power loss within the component
- R_{th} is the internal resistance of the component

The first step is to find the amount of energy needed to be dissipated in the resistor:

- Energy (450 V) = 0.5 x C x V^2 = 0.5 x $600e^{-6}$ x $(450)^2$ = 60.75 Ws(J)
- Energy (60 V) = 0.5 x C x V^2 = 0.5 x $600e^{-6}$ x $(60)^2$ = 1.08 Ws(J)
- Energy pulse = energy (450 V) - energy (60 V) = 60.75 - 1.08 ~ 60 Ws(J)

The following steps must be followed in order to confirm that the resistance will be able to discharge the energy without reaching the cross-over point. The cross-over point is the time at which significant energy starts to be dissipated not only in the resistance wire itself, but also into the core, leads, and encapsulation material.

<u>Recommended Steps</u>

[1] Get the number of resistors (NR) and dT for energy input of 1 pulse in $\tau/2$

[2] Calculate dT for energy input of 2 pulses in 10 s in one resistor

[3] Add both dTs and add T_{amb} and check if T < 400 °C is ok

It is highly recommended to perform these steps with Vishay’s technical support team. Customers may contact the technical support team at ww1resistors@vishay.com.

It is always recommended to perform the previous steps at the worst case ambient temperature, which is 80 °C in this reference design.

TABLE 3 - SUMMARY OF RESISTANCE TYPES AND RESISTANCE COUNTS				
RESISTANCE TYPE	**PART NUMBER**	**R (Ω)**	**P_R (W)**	**N_R**
AC95AT	AC05AT0K09109JBW00	91	5	1
AC10AT	AC10AT0009109JAB00	91	10	1
LTO100	LTO100F10000JTE3	1000	100	1
CMB0207	CMB02070X1501GB200	1500	1	16

2.5. Testing Procedure

The following steps need to be followed strictly to test each one of the proposed reference designs:

1. Connect DCLINK+ to the positive terminal of a DC-Link capacitor and DCLINK- to the negative terminal of a DC-Link capacitor. The user must take all precautions and make these connections in a safe sequence. The capacitor must be discharged before making this connection
2. Make sure that the #2 “Discharge” pin is connected to the 0 V pin in J1
3. Charge the capacitor carefully using an external supply to the required voltage (please revisit the absolute maximum ratings)
4. To enable the discharge, pull pin #2 “Discharge” on J1 to high

Individual discharge curves can be found in Fig. 7.

TYPICAL APPLICATION CIRCUIT

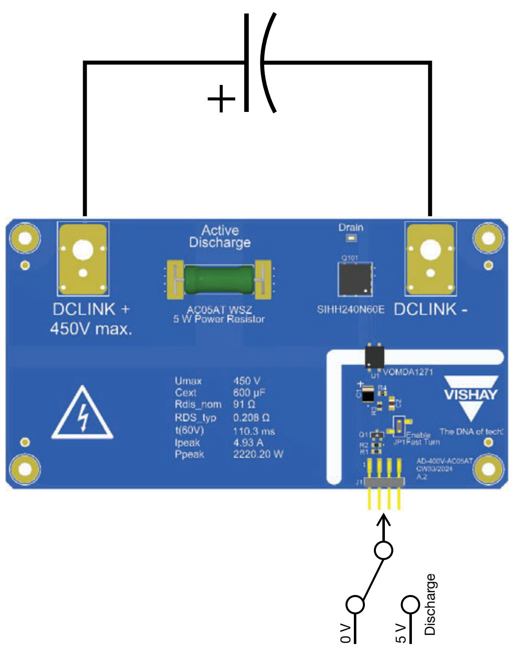


Fig. 3 - Typical Application Circuit Using a Two-Way Switch

PIN CONFIGURATION

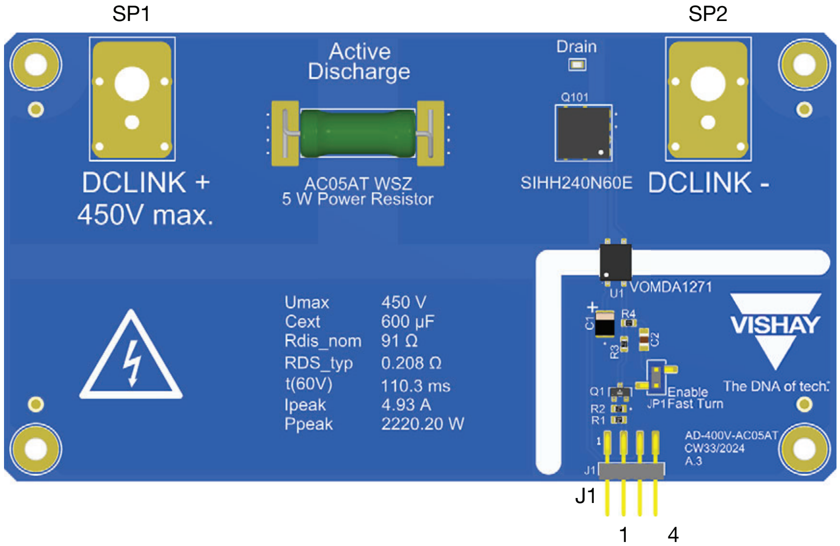


Fig. 4

PIN DESCRIPTION		
PIN NUMBER	**SYMBOL**	**DESCRIPTION**
SP1	DCLINK+	Connect with HV DC voltage input; max. 450 V
SP2	DCLINK-	Connect with reference point for DC Input
J1 / 1	N.C	Not connected
J1 / 2	Discharge	Active high discharge signal
J1 / 3	VCC	Connect with supply voltage +5 V
J1 / 4	GND	GND for supply voltage

ELECTRICAL CHARACTERISTICS

RECOMMENDED OPERATING RANGE			
PARAMETER	**MIN.**	**MAX.**	**UNIT**
DCLINK+ to DCLINK-	25	450	V
V_{CC} to GND	4.5	5.5	V

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)		
ELECTRICAL PARAMETER	**LIMITS**	**UNIT**
HV U_{DC} to ref.	450	V
V_{CC} to GND	-0.3 to +6.0	V
Ambient temperature	-40 to 125	°C
Storage temperature	-40 to 150	°C
Max. power consumption	1500	mW
Max. current consumption	300	mA
Isolation voltage	5000	V_{RMS}

DERATING

The resistor's power dissipation causes it to heat up. To prevent overheating, the maximum allowable power output decreases at temperatures above the derating temperature, as shown in the derating curves. This heat can also affect nearby components, so adequate spacing is necessary. Fig. 5 and Fig. 6 show different derating curves for different resistor types.

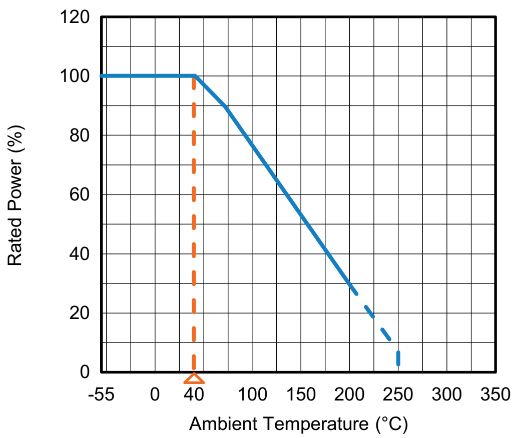


Fig. 5 - Derating Curves for ACT Resistors

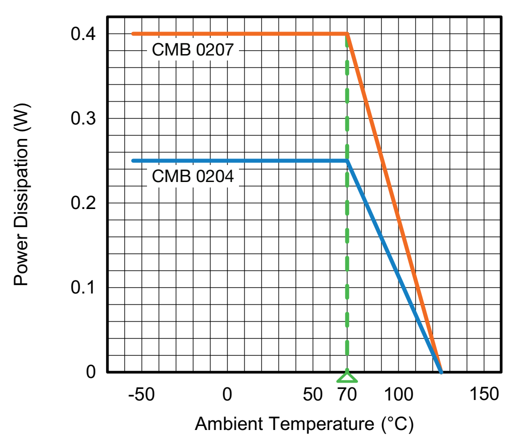
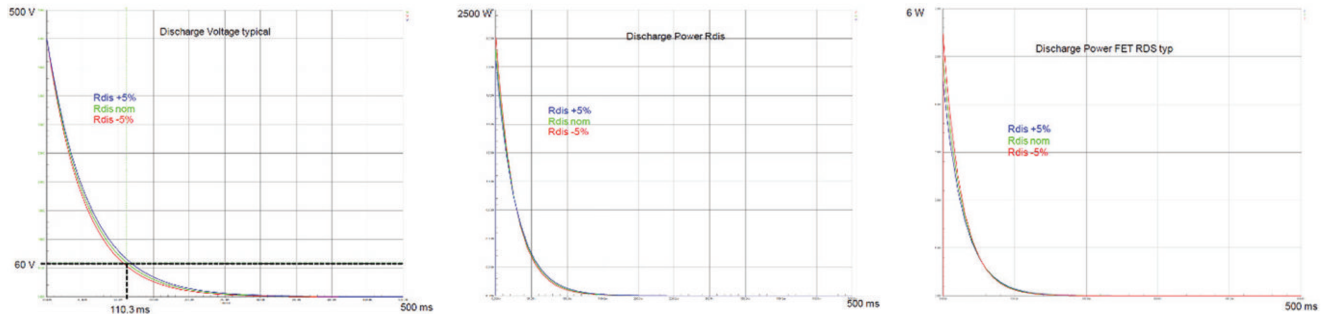


Fig. 6 - Derating Curves for CMB Resistors

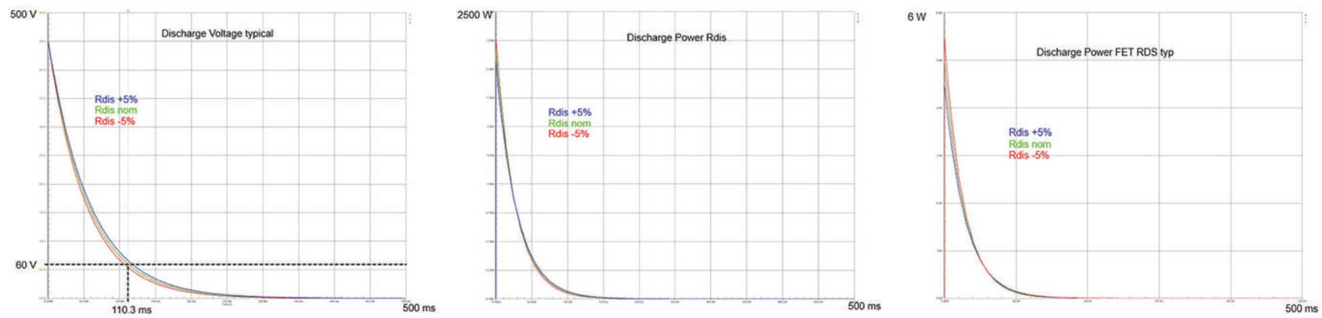
ELECTRICAL CHARACTERISTICS

AD-400V-AC05AT



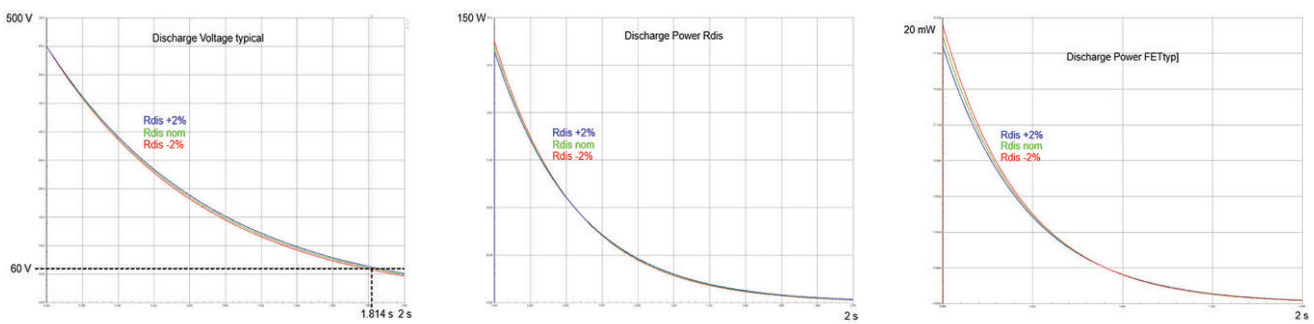
(a) (b) (c)

AD-400V-AC10AT



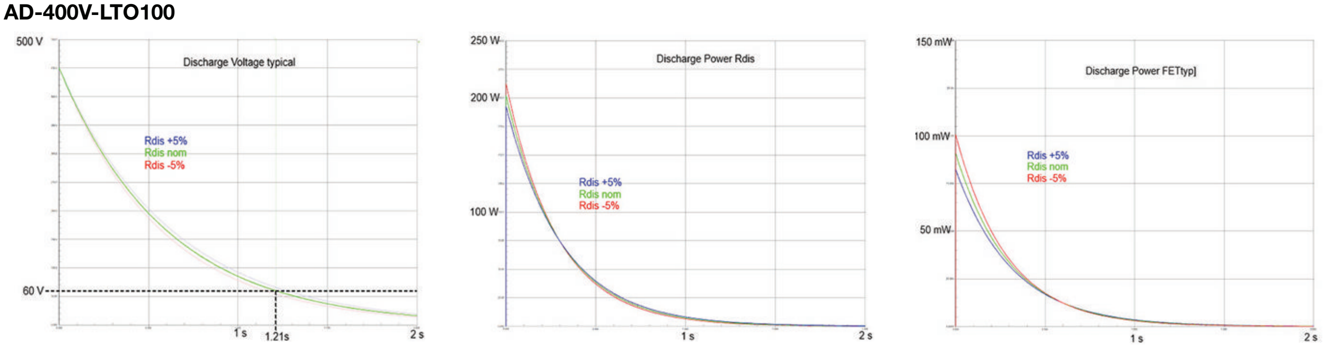
(a) (b) (c)

AD-400V-CMB0207



(a) (b) (c)

AD-400V-LTO100



(a) (b) (c)

Fig. 7 - Discharge Curves for Individual Designs

DIMENSIONS

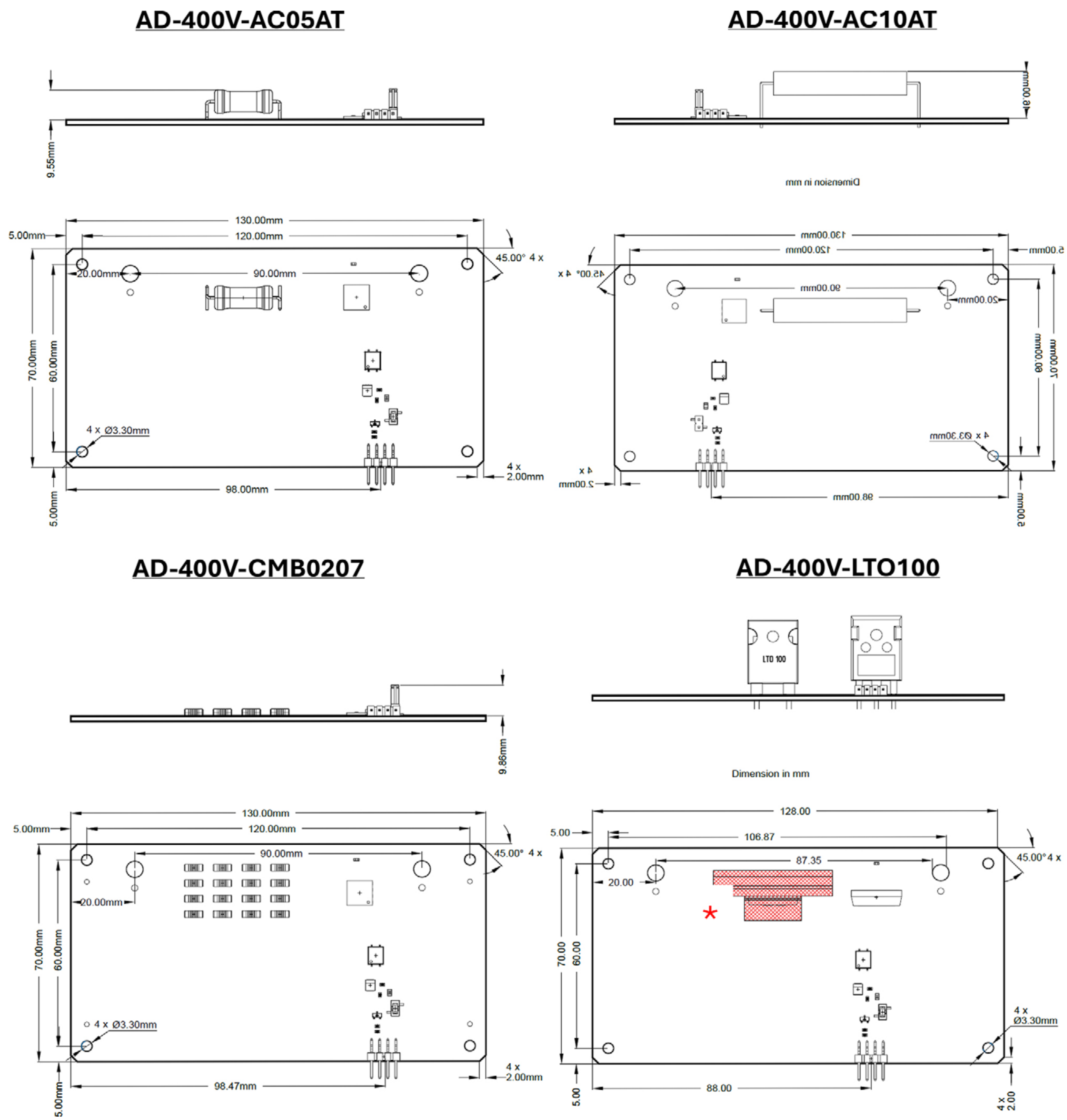


Fig. 8 - Discharge Curves for Individual Designs

Note

- Heatsink is not provided, the customer may decide to use one if the application requires it

AVAILABLE REFERENCE DESIGN KITs

REFERENCE DESIGN	DESCRIPTION
AD-400V-AC05AT	Active discharge reference design works at 400 V using AC05AT wirewound resistor
AD-400V-AC10AT	Active discharge reference design works at 400 V using AC10AT wirewound resistor
AD-400V-CMB0207	Active discharge reference design works at 400 V using CMB0207carbon film MELF resistors
AD-400V-LTO100	Active discharge reference design works at 400 V using LTO100 Thick Film Technology resistors

BOM

A detailed BOM for each design is provided in the application folder in this link.

ADDITIONAL RESOURCES

[1] Pulse Handling Capabilities of Vishay Dale Wirewound Resistors

[2] Thermal Management in Surface-Mounted Resistor Applications

[3] VOMDA1271 Application Note (EV06)

[4] SiHH240N60E Datasheet

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