AAT4631/4631-1

High Power Adjustable Current Limited Load Switch with Fault Flag

General Description

The AAT4631/AAT4631-1 SmartSwitch are high power current limited P-channel MOSFET power switches designed for high side load switching applications. The switches operate with inputs ranging from 2.4V to 5.5V, making them ideal for both 3V and 5V systems. An integrated current-limiting circuit protects the input supply against large currents which may cause the supply to fall out of regulation. Reverse current blocking is provided to protect the load switch from reverse current potentials while the device is shutdown.

The AAT4631/AAT4631-1 are also protected from thermal overload which is limited by power dissipation and junction temperatures.

Current limit threshold of AAT4631 is programmed from 500mA to 3.1A with a resistor from SET to ground. The current limit threshold can also be removed to allow up to 3A continuous and 4A peak current to flow through the load switch by shorting the SET pin to ground (This function is the same as AAT4631). The ultra-fast current limit response to a sudden short circuit is a mere 1µs which reduces the requirements of local supply bypassing.

An open drain fault flag (FLT) in AAT4631/AAT4631-1 signals an over-current or over-temperature condition after a 5ms blanking time to prevent false reporting. Quiescent current is a low 10µA and the supply current decreases to less than 1µA in shutdown mode.

The AAT4631/AAT4631-1 are offered in the small Pb-free, 10-pin TDFN2222-10 package, and are specified for operation over the -40°C to +85°C ambient temperature range.

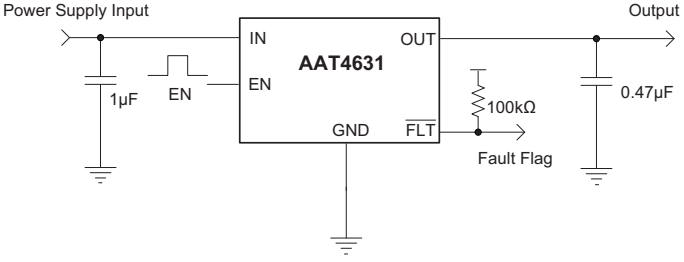
Features

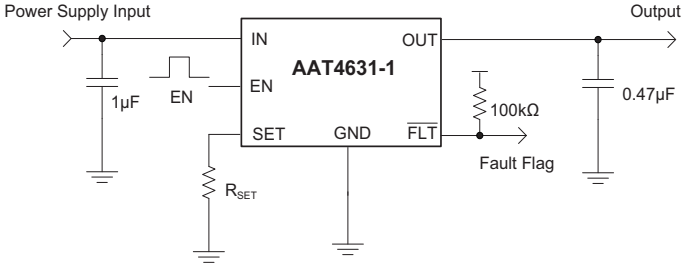
- 3A Continuous, 4A Peak Current Capability
- Reverse Blocking During Disable
- Input Voltage Range: 2.4V to 5.5V
- Programmable Over-Current Threshold: 500mA to 3.1A (AAT4631-1 only)
- Fast Transient Response:
  - 1µs Response to Short Circuit (AAT4631-1 only)
- Low Quiescent Current
  - 10µA Typical while Enabled
  - 1µA Max with Switch Off (T_A = 25°C)
- 90mΩ Typical $R_{DS(ON)}$
- Under-Voltage Lockout
- 5ms Fault Blanking
- Fault Flag Open Drain Output
- Active Hi Enable
- Over-Temperature Protection
- 1.5ms Soft Start
- 10 Pin TDFN2222-10 Package
- Temperature Range: -40°C to +85°C

Applications

- Hot Swap Supplies
- Notebook Computers
- Portable Products
- Proprietary Peripheral Ports
- USB Ports

Typical Application



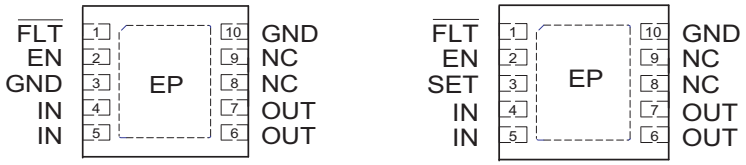


Pin Description

Pin #		Symbol	Description
AAT4631	AAT4631-1		
1	1	$\overline{FLT}$	Current limit fault flag pin, open-drain output, active low signal. Pull up with a 10kΩ to 100kΩ resistor.
2	2	EN	Load switch enable input. Active high signal.
	3	SET	Current limit set pin. Connect a resistor between this pin and ground to program the desired current limit set point. Short to ground if no current limit setting is required. SET pin must not be left floating.
4, 5	4, 5	IN	Load switch power supply input pin (high side P-channel MOSFET source). Bypass with a 1µF capacitor from IN to GND.
6, 7	6, 7	OUT	Current limiting load switch output (high side P-channel MOSFET Drain). Connect a 0.47µF capacitor from OUT to GND for best load transient response.
8, 9,	8, 9,	NC	No Connection
3,10	10	GND	IC ground connection. Need to connect to GND.
EP	EP		Exposed paddle. Connect to PCB GND plane.

Pin Configuration

TDFN2222-10
(Top View)



AAT4631 **AAT4631-1**

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Absolute Maximum Ratings[1]

Symbol	Description	Value	Units
V_{IN}	IN to GND	-0.3 to 6	V
V_{EN},V_{FLT}	EN, $\overline{FLT}$ to GND	-0.3 to V_{IN} + 0.3	
V_{OUT}, V_{SET}	OUT, SET to GND	-0.3 to V_{IN} + 0.3	
I_{MAX_DC}	Maximum DC Output Current[2]	3.5	A
I_{MAX_PULSE}	Maximum Pulse Output Current*	4	
V_{ESD}	ESD Rating, HBM	4	kV
T_J	Maximum Junction Operating temperature	-40 to +150	°C
T_{LEAD}	Maximum Soldering Temperature (at leads, 10 sec)	300	

Thermal Information

Symbol	Description	Value	Units
P_D	Maximum Power Dissipation[2,3]	1381	mW
θ_{JA}	Maximum Thermal Resistance[3]	72.43	°C/W

* Pulse duration must be less than 300µs and period longer than 4ms.

1. Stresses above those listed in Absolute Maximum Ratings may cause permanent damage to the device. Functional operation at conditions other than the operating conditions specified is not implied.
2. Mounted on FR4 circuit board.
3. Derate 13.8mW/°C above 40°C ambient temperature

Electrical Characteristics

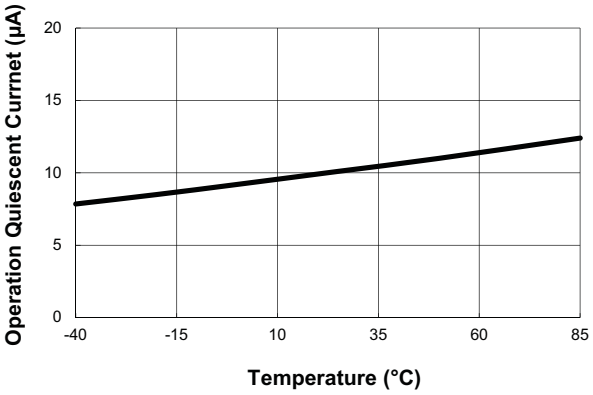
V_{IN} = 5V; T_A = -40°C to 85°C unless otherwise noted. Typical values are at T_A = 25°C.

Symbol	Description	Conditions		Min	Typ	Max	Units
V_{IN}	Input Voltage Range			2.4		5.5	V
I_Q	Operation Quiescent Current	V_{IN} = 5V, EN = Active, I_{OUT} = 0			10	25	µA
$I_{Q(OFF)}$	Off Supply Current	EN = Inactive, V_{IN} = 5.5V. No load			0.01	1	
$I_{SD(OFF)}$	Off Switch Current	EN = Inactive, V_{IN} = 5.5V, V_{OUT} = 0V			0.01	1	
$I_{REVERSE}$	Reverse Blocking Current	V_{IN} = 3.7V, V_{OUT} = 4.2V, EN = Inactive				2	
V_{UVLO}	Under-Voltage Lockout	Rising edge			1.8	2.4	V
V_{UVLO_HYS}	Under-Voltage Lockout Hysteresis				0.1		
$R_{DS(ON)}$	On-Resistance	V_{IN} = 5.0V, T_A = 25°C			75	120	mΩ
		V_{IN} = 3.0V, T_A = 25°C			90	150	
TC_{RDS}	On-Resistance Temperature Coefficient				2800		ppm/°C
I_O	Maximum Continuous Output Current	R_{SET} = 0Ω[1]			3		A
I_{LIM}	Current Limit (only for AAT4631-1)	R_{SET} = 1.1kΩ, V_{OUT} = V_{IN} - 0.5V		2.25	3	3.75	
$V_{EN(L)}$	EN Input Low Voltage	V_{IN} = 2.7V to 5.5V				0.6	V
$V_{EN(H)}$	EN Input High Voltage	V_{IN} = 2.7V to <4.2V		2.0			
		V_{IN} ≥ 4.2V to 5.5V		2.4			
$I_{EN(SINK)}$	Input Leakage Current	V_{EN} = 5.5V			0.01	1	µA
t_{RESP}	Current Limit Response Time	V_{IN} = 5V			1		µs
$t_{D(ON)}$	Output Turn On Delay Time	V_{IN} = 5V, R_{SET} = 0Ω[1], R_O = 10Ω			3		ms
t_{ON}	Turn On Rising Time	V_{IN} = 5V, R_{SET} = 0Ω[1], R_O = 10Ω		1	1.5		
t_{OFF}	Turn Off Time	V_{IN} = 5V, R_O = 10Ω			55	100	µs
T_{SD}	Over-Temperature Shutdown Threshold	V_{IN} = 5V, I_{LOAD} > 0.5A	T_J Increasing		140		°C
			T_J Decreasing		115		
t_{BLANK}	Fault Flag Blanking Time				5		ms
$V_{FLT(LO)}$	Fault Flag Logic Low Output	$I_{FLT(SINK)}$ = 1mA				0.4	V
$I_{FLT(SINK)}$	Fault Flag Logic High Leakage Current				0.5	1	µA

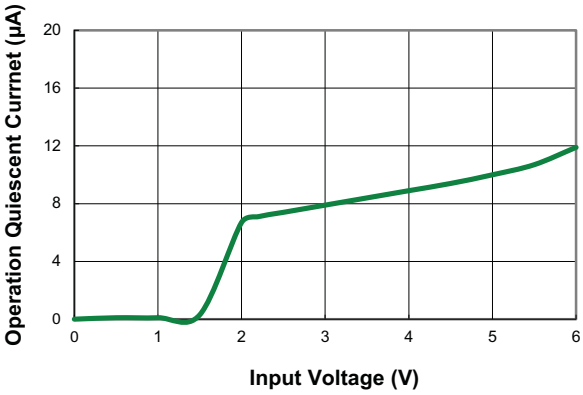
1. R_{SET} = 0 is only for AAT4631-1.

Typical Characteristics

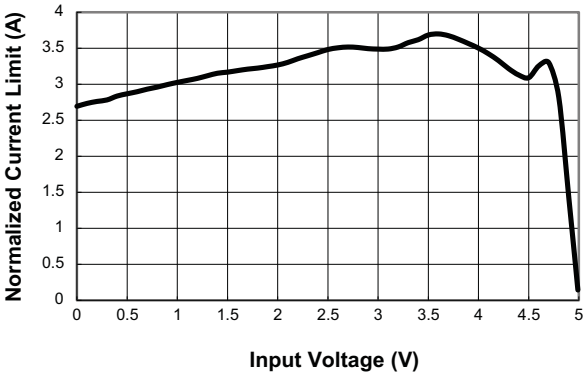
Operation Quiescent Current vs Temperature



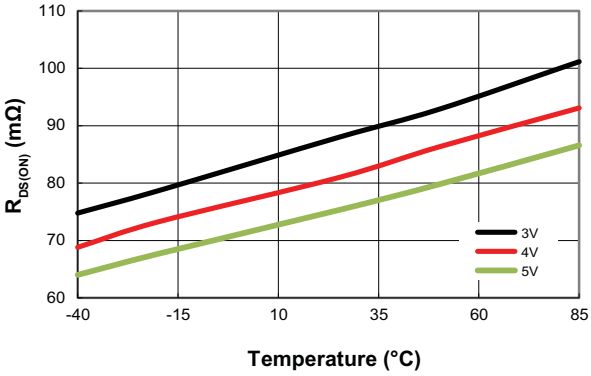
Operation Quiescent Current vs Input Voltage



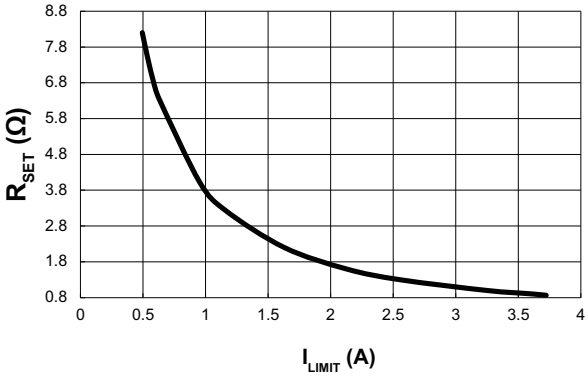
Output Current vs Output Voltage
(R_{SET} = 1.1kΩ) (AAT4631-1 Only)



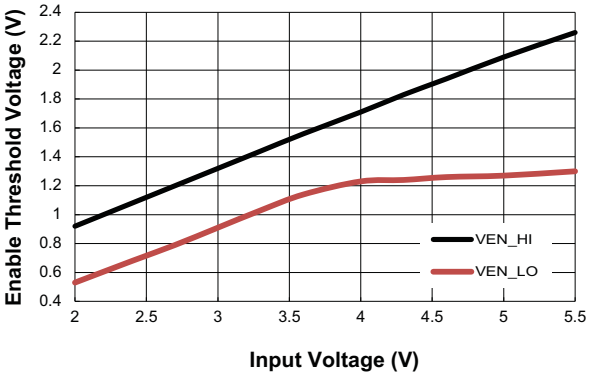
$R_{DS(ON)}$ vs Temperature
(I_{LOAD} = 1.0A)



R_{SET} vs I_{LIMIT}
(AAT4361-1 - Only)

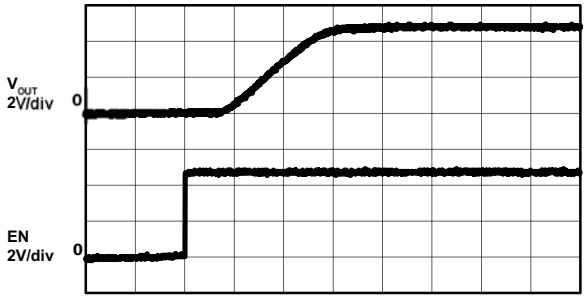


EN Threshold vs Input Voltage



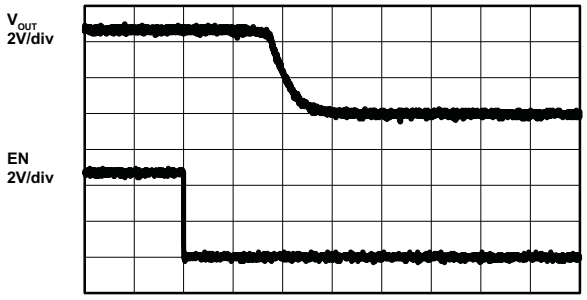
Typical Characteristics

Turn - On
(V_{IN} = 5V; R_L = 10Ω; C_L = 0.47µF)



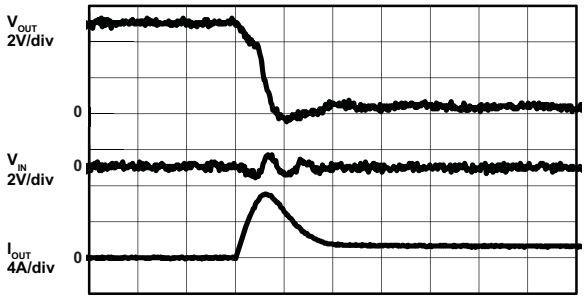
Time (800µs/div)

Turn-Off
(V_{IN} = 5V; R_L = 10Ω; C_L = 0.47µF)



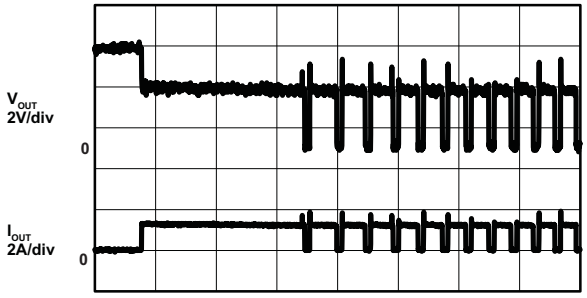
Time (800µs/div)

Short Circuit Through 0.3Ω
(R_{SET} = 3.74kΩ)(AAT4631-1 - Only)



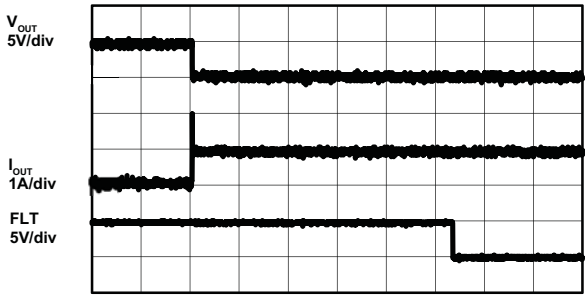
Time (2µs/div)

Thermal Shutdown Response
(R_L = 10Ω, C_L = 0.47µF)



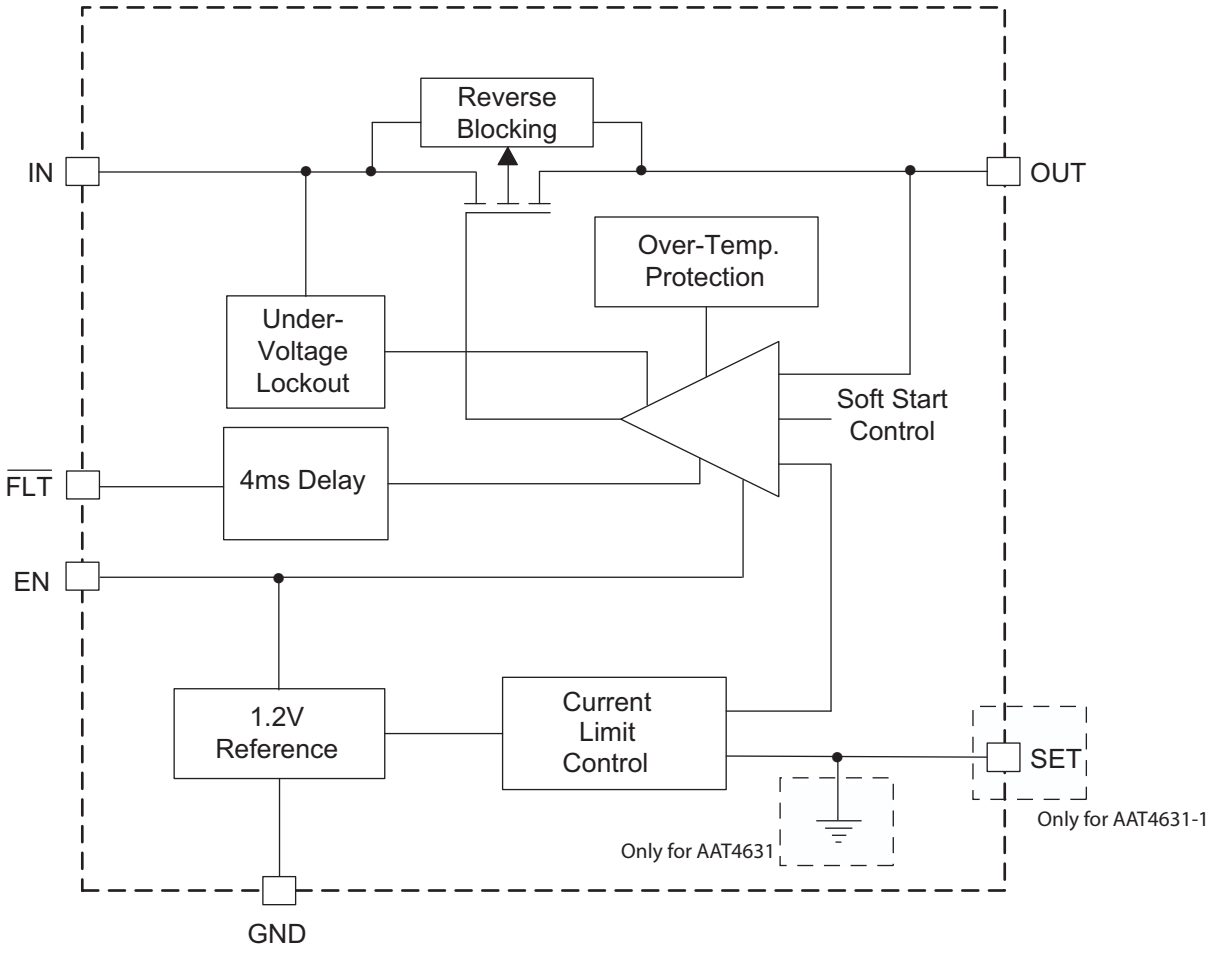
Time (500ms/div)

Fault Delay from Short Circuit
(R_{SET} = 3.74kΩ)(AAT4631-1 - Only)



Time (1ms/div)

Functional Block Diagram



Functional Description

The AAT4631/AAT4631-1 are single channel load switches. The devices provide a reverse current blocking feature, ON/OFF enable control, soft start, and a fault flag to notify a system controller of over-current, short-circuit or over-temperature events.

The programmable current limit function in AAT4631-1 is intended to protect against short-circuit and over-current events by current limiting to a preset level.

In the event of a load current exceeding a user programmed current limit level (I_{LIM}), a high speed current limit loop limits the current in a microsecond and will reset to low impedance once the short-circuit condition is removed.

To eliminate startup inrush current, a soft-start block prevents the V_{OUT} from reaching the input voltage level by more than 1ms to limit the inrush current occuring at the input. The AAT4631/AAT4631-1 are internally protected from thermal damage by an over-temperature detection circuit. If the die temperature reaches the internal thermal limit, the power device is switched off until the die temperature cools down to a level below the thermal limit threshold. The devices may operate in a thermal cycling state indefinitely or until the over-current condition is removed.

Application Information

Setting the Current Limit (AAT4631-1 only)

In most applications, the variation in I_{LIM} must be taken into account when determining R_{SET}. The I_{LIM} variation is due to processing variations from part to part, as well as variations in the voltages at IN and OUT, plus the operating temperature. Together, these three factors add up to a ±25% tolerance (see I_{LIM} specification in "Electrical Characteristics" section). Figure 1 illustrates a cold device with a statistically higher current limit and a hot device with a statistically lower current limit, both with R_{SET} equal to 1.1kΩ. While the chart, "R_{SET} vs. I_{LIM}" indicates an I_{LIM} of 3A with an R_{SET} of 1.1kΩ, this figure shows that the actual current limit will be at least 2.25A and no greater than 3.75A.

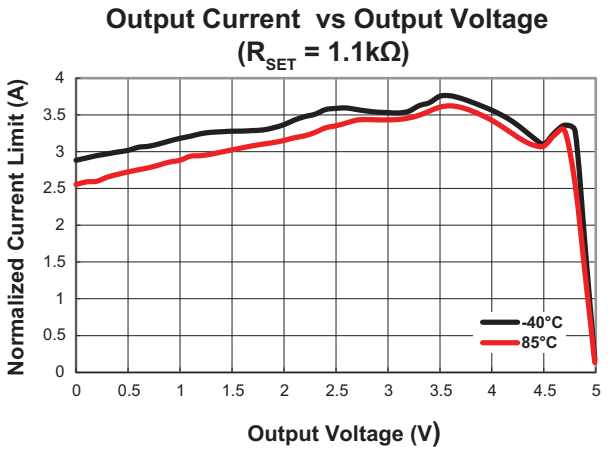


Figure 1: Current Limit at High and Low Temperature Using 1.1kΩ.

To determine R_{SET}, start with the application required current limit as the minimum current limit value and multiply it by 1.33 to derive the typical current limit value.

Next, refer to Table 1 to find the approximate R_{SET} value. For greater precision, use the small current limit range linear approximation to calculate R_{SET} value. For example, for 2.3A current limit requirement, first calculate the typical current limit: 2.3A · 1.33 = 3.059A. Then using table 1, the nearest small current limit range is 3A to 3.1A with 0.1A current limit interval and -0.045kV $R_{SET} \cdot I_{LIM}$ coefficient interval. Then adopt the method of linear approximation in small range to calculate the $R_{SET} \cdot I_{LIM}$ coefficient.

$$R_{SET} \cdot I_{LIM} = 3.3 - \frac{(-0.045) \cdot (3.059 - 3)}{0.1} = 3.327\ (kV)$$

$$R_{SET} = \frac{3.327kV}{3.059A} = 1.087\ (k\Omega)$$

Referring to the standard resistor table, we can select 1.1kΩ ±1% metal film resistor.

Standard R_{SET} (kΩ)	I_{LIM} Typ. (A)	$R_{SET} \cdot I_{LIM}$ Coefficient (kV)
7.68	0.5	3.840
6.34	0.6	3.804
5.49	0.7	3.843
4.75	0.8	3.800
4.22	0.9	3.798
3.74	1	3.740
3.4	1.1	3.740
3.09	1.2	3.708
2.8	1.3	3.640
2.55	1.4	3.570
2.37	1.5	3.555
2.21	1.6	3.536
2.05	1.7	3.485
1.96	1.8	3.528
1.82	1.9	3.458
1.74	2	3.480
1.62	2.1	3.402
1.54	2.2	3.388
1.47	2.3	3.381
1.4	2.4	3.360
1.33	2.5	3.325
1.28	2.6	3.328
1.21	2.7	3.267
1.18	2.8	3.304
1.13	2.9	3.277
1.1	3	3.300
1.05	3.1	3.255

Table 1: Current Limit Standard R_{SET} Value.

Input Capacitor

The input capacitor C_{IN} protects the power supply from current transients generated by the load attached to the AAT4631/AAT4631-1. When a short circuit is suddenly applied to the output of the AAT4631/AAT4631-1, a large current limited only by the $R_{DS(ON)}$ of the MOSFET, will flow for less than 1µs before the current limit circuitry activates. In this event, a moderately sized C_{IN} will dramatically reduce the voltage transient seen by the power supply and by other circuitry upstream from the

AAT4631/AAT4631-1. The extremely fast short-circuit response time of the AAT4631/AAT4631-1 reduces the size requirement for C_{IN}.

C_{IN} should be located as close to the device IN pin as practically possible. Ceramic, tantalum, or aluminum electrolytic capacitors are appropriate for C_{IN}. There is no specific capacitor ESR requirement for C_{IN}. However, for higher current operation, ceramic capacitors are recommended for C_{IN} due to their inherent capability over tantalum capacitors to withstand input current surges from low impedance sources such as batteries in portable devices.

Output Capacitor

In order to insure stability while current limit is active, a low capacitance (approximately 0.47µF) is required. No matter how large the output capacitor, output current is limited to the value set by the AAT4631/AAT4631-1 current limiting circuitry, so very large output capacitors can be used. For example, USB ports are specified to have at least 120µF of capacitance downstream from their controlling power switch. The current limiting circuit will allow an output capacitance of 1000µF or more without disturbing the upstream power supply.

Enable Function

In many systems, power planes are controlled by integrated circuits which run at lower voltages than the power planes themselves. The enable input (EN) of the AAT4631/AAT4631-1 has low and high threshold voltages that accommodate this condition. The threshold voltages are compatible with 5V TTL and 2.5V to 5V CMOS systems.Both active high and active low options are available for all packages.

Connecting to Capacitive Load

When switching the AAT4631/AAT4631-1 onto a capacitive load, the AAT4631/AAT4631-1 will charge the output capacitive load at a rate no greater than the current limit setting.

FAULT Output

The FAULT Flag ($\overline{FLT}$) is provided to alert the system if an AAT4631/AAT4631-1 load is not receiving sufficient voltage to operate properly. If current limit or over-temperature circuits in any combination are active for more than approximately 5ms, the FAULT Flag is pulled to ground through an approximately 100Ω resistor. The filtering of voltage or current transients of less than 4ms prevents capacitive loads connected to the AAT4631/AAT4631-1 output from activating the FAULT Flag when they are initially attached. Pull-up resistances of 1kΩ to 100kΩ are recommended. Since FLT is an open drain terminal, it may be pulled up to any unrelated voltage less than the maximum operating voltage of 5.5V, allowing for level shifting between circuits.

Thermal Considerations

Since the AAT4631/AAT4631-1 have internal current limit and over-temperature protection, junction temperature is rarely a concern. However, if the application requires large currents in a hot environment, it is possible that temperature, rather than current limit, will be the dominant regulating condition. In these applications, the maximum current available without risk of an over-temperature condition must be calculated. The maximum internal temperature while current limit is not active can be calculated using Equation 1.

$$T_{J(MAX)} = I^2_{MAX} \cdot R_{DS(ON)(MAX)} \cdot R_{\theta JA} + T_{A(MAX)}$$

where I_{MAX} is the maximum current required by the load. $R_{DS(ON)(MAX)}$ is the maximum rated $R_{DS(ON)}$ of the AAT4631/AAT4631-1 at high temperature. $R_{\theta JA}$ is the thermal resistance between the AAT4631/AAT4631-1 die and the board onto which it is mounted. $T_{A(MAX)}$ is the maximum temperature that the PCB under the AAT4631/AAT4631-1 would be if the AAT4631/AAT4631-1 were not dissipating power. The following equation can be rearranged to solve for I_{MAX}.

$$I_{MAX} = \sqrt{\frac{T_{SD(MIN)} - T_{A(MAX)}}{R_{DS(ON)(MAX)} \cdot R_{\theta JA}}}$$

where $T_{SD(MIN)}$ is the minimum temperature required to activate AAT4631/AAT4631-1's over-temperature protection. With the typical specification of 140°C, 115°C is a safe minimum value to use.

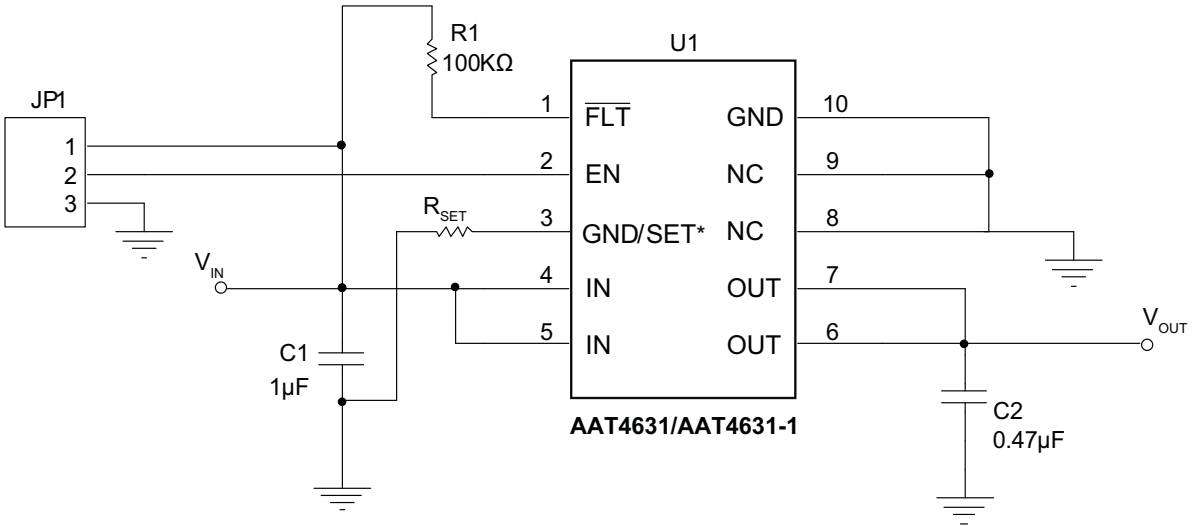
For example, if an application is specified to operate in 50°C environments, the PCB operates at temperatures as high as 85°C. The application is sealed and its PCB is small, causing $R_{\theta JA}$ to be approximately 72.43°C/W. Using the following equation:

$$I_{MAX} = \sqrt{\frac{115 - 85}{0.15 \cdot 72.43}} = 1.66(A)$$

Evaluation Board

The evaluation board schematic is shown in Figure 2.

The PCB layout is shown in Figures 3 and 4. The bill of materials (BOM) for the board is shown in Table 2 and Table 3.



*GND is only for AAT4631; SET is only for AAT4631-1.

Figure 2: AAT4631/AAT4631-1 Evaluation Board Schematic.

Component	Part Number	Description	Manufacture
C1	GRM188R71A474K	CAP CERAMIC 0.47µF 0603 X7R 10V 10%	Murata
C2	GRM188R71C105K	CAP CERAMIC 1µF 0603 X7R 16V 10%	
R1	RC0603JR-07100KL	100K, 1/16W 5% 0603 SMD	Yageo
RSET	RC0603-070RL	0Ω, 1/16W 5% 0603 SMD	
U1	AAT4631IDH-2-T1	Load Switch	Skyworks
JP1		Device Enable/Disable Selector	

Table2: AAT4631 Evaluation Board Bill of Materials (BOM).

Component	Part Number	Description	Manufacture
U1	AAT4631-1IDH-2-T1	Load Switch	Skyworks
C1	GRM188R71A474K	CAP CERAMIC 0.47µF 0603 X7R 10V 10%	Murata
C2	GRM188R71C105K	CAP CERAMIC 1µF 0603 X7R 16V 10%	
R1	RC0603JR-07100KL	100K, 1/16W 5% 0603 SMD	Yageo
RSET	RC0603FR-071K1L	1.1K, 1/16W 1% 0603 SMD	
JP1		Device Enable/Disable Selector	

Table3: AAT4631-1 Evaluation Board Bill of Materials (BOM).

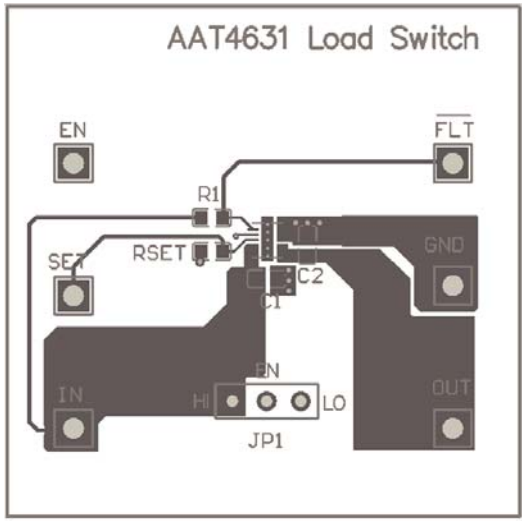


Figure 3: AAT4631/AAT4631-1 Evaluation Board PCB Top Side.

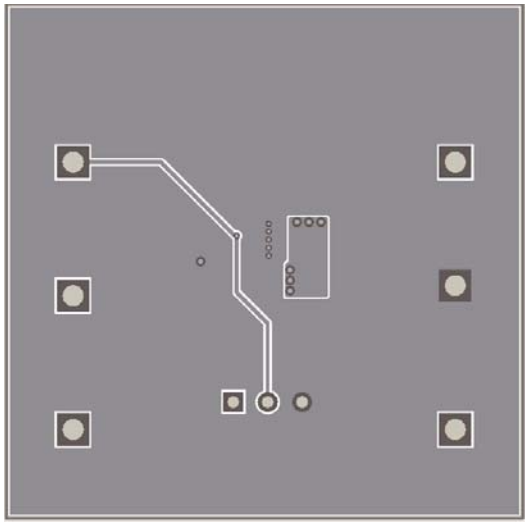


Figure 4: AAT4631/AAT4631-1 Evaluation Board PCB Bottom Side.

PCB Layout Guideline

1. To maximize package thermal dissipation and power handling capacity, solder the exposed paddle of the IC onto the thermal landing of the PCB, where the thermal landing is connected to the ground plane. Also, adding more thermal vias on the thermal landing helps transfer heat to the PCB effectively.

2. All of the GND pins of IC need to connect to GND.

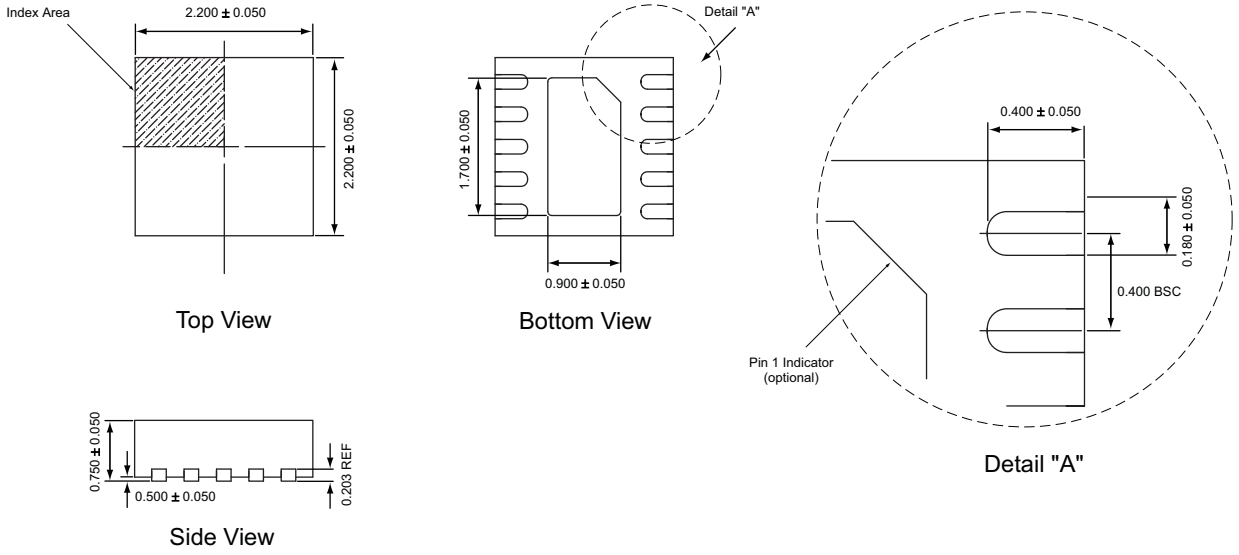
Ordering Information

Package	Marking[1]	Part Number (Tape and Reel)[2]
TDFN2222-10	X3XYY	**AAT4631IDH-T1**
TDFN2222-10	W8XYY	**AAT4631IDH-1-T1**

Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to *Skyworks Definition of Green™*, document number SQ04-0074.

Package Information

TDFN2222-10



All dimensions in millimeters.

1. XYY = assembly and date code.
2. Sample stock is generally held on part numbers listed in BOLD.