DATA SHEET

AAT4616A: High Precision Adjustable Current Limited Load Switch with Fault Flag

Applications

- USB ports
- Portable products
- Hot-swap supplies
- Notebook computers
- Proprietary peripheral ports

Features

- Input voltage: 2.4 V to 5.5 V
- Programmable over-current limit setting: 300 mA to 1.6 A
- ±10% current limit precision at 750 mA
- Fast transient response: 2 μs response to short circuit
- Low quiescent current
  - 10 μA typical while enabled
  - 1 μA maximum with switch off
- 130 mΩ typical $R_{DS(ON)}$
- Under-Voltage Lockout (UVLO)
- Reverse blocking during disable
- 4 ms fault blanking
- Fault flag open-drain output
- Active high/low enable options
- Over-temperature protection
- Temperature range: –40 °C to +85 °C
- TDFN (6-pin, 2 x 2 mm) package (MSL1, 260 °C per JEDEC-J-STD-020)

Description

The AAT4616A SmartSwitch is a current-limiting P-channel MOSFET power switch designed for high side load switching applications. This switch operates with inputs ranging from 2.4 V to 5.5 V, making it ideal for both 3 V and 5 V systems. An integrated current-limiting circuit protects the input supply against large currents that 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 AAT4616A is also protected from thermal overload which is limited by power dissipation and junction temperatures. The current limit threshold is programmed with a resistor from SET to ground and may be adjusted for levels up to 1.6 A. The ultra-fast current limit response to a sudden short circuit is a mere 2 μs, which reduces the requirements of local supply bypassing. An open drain FAULT flag signals an over-current or over-temperature condition after a 4 ms blanking time to prevent false reporting. Quiescent current is as low as 10 μA and the supply current decreases to less than 1 μA in shutdown mode.

The AAT4616A is offered in a small Thin, Dual Flat No-Lead (TDFN22-6) package. A typical application circuit is shown in Figure 1. The pin configuration is shown in Figure 2. Signal pin assignments and functional pin descriptions are provided in Table 1.

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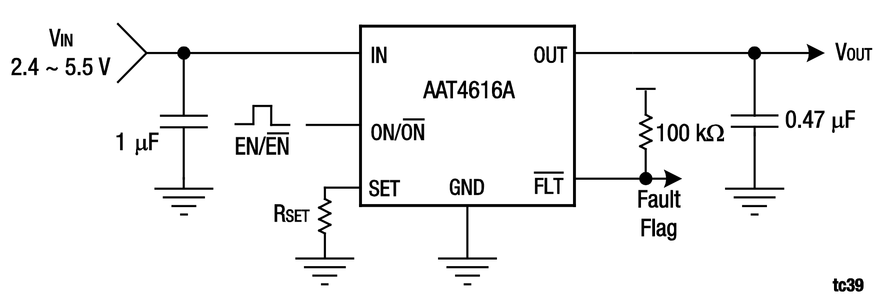


Figure 1. AAT4616A Typical Application Circuit

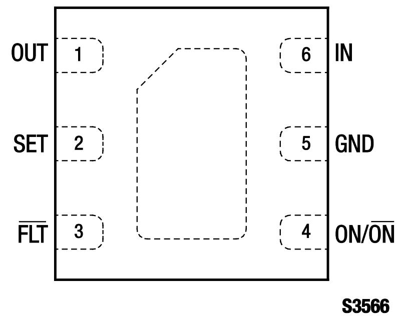


Figure 2. AAT4616A TDFN22-6 (Top View)

Table 1. AAT4616A Signal Descriptions

Pin #	Name	Description
1	OUT	Current limiting load switch output (high side P-channel MOSFET drain). Connect a 0.47 μF capacitor from OUT to GND for best load transient response.
2	SET	Current limit set pin. Connect a resistor between this pin and ground to program the desired current limit set point.
3	$\overline{FLT}$	Current limit fault flag pin, open-drain output, active low signal. Pull up with a 10 kΩ to 100 kΩ resistor.
4	ON/$\overline{ON}$	Load switch enable input. Active high and active low options are available.
5	GND	Ground
6	IN	Load switch power supply input pin (high side P-channel MOSFET source). Bypass with a 1 μF capacitor from IN to GND.

Table 2. AAT4616A Absolute Maximum Ratings (Note 1)

Parameter	Symbol	Minimum	Typical	Maximum	Units
IN to GND	V_{IN}	−0.3		+6.0	V
ON/$\overline{ON}$,$\overline{FLT}$ to GND	V_{ON}, V_{FLT}	−0.3		V_{IN} + 0.3	V
SET, OUT to GND	V_{SET}, V_{OUT}	−0.3		V_{IN} + 0.3	V
Maximum DC output current (Note 2)	I_{MAX}			2	A
Operating junction temperature range	T_J	−40		+150	°C
Storage temperature range	T_{STG}	−40		+150	°C
Maximum Soldering Temperature (at leads)	T_{LEAD}			300	°C
Thermal resistance	θ_{JA}		85		°C/W
Power dissipation (Note 3)	P_D		1.18		W

Note 1: Exposure to maximum rating conditions for extended periods may reduce device reliability. There is no damage to device with only one parameter set at the limit and all other parameters set at or below their nominal value. Exceeding any of the limits listed may result in permanent damage to the device.

Note 2: The current rating is based on long-term current density limitations.

Note 3: Mounted on an FR4 board. Derated 11.8 mW/ °C above 25 °C.

***CAUTION**: Although this device is designed to be as robust as possible, Electrostatic Discharge (ESD) can damage this device. This device must be protected at all times from ESD. Static charges may easily produce potentials of several kilovolts on the human body or equipment, which can discharge without detection. Industry-standard ESD precautions should be used at all times.*

Electrical and Mechanical Specifications

The absolute maximum ratings of the AAT4616A are provided in Table 2. The recommended operating conditions are specified in Table 3, and electrical specifications are provided in Table 4.

Typical performance characteristics of the AAT4616A are illustrated in Figures 3 through 14.

Table 3. Recommended Operating Conditions

Parameter	Symbol	Minimum	Typical	Maximum	Units
Input voltage	V_{IN}	2.4		5.5	V
High-level Input voltage	$V_{ON(H)}$	1.4			V
Low-level Input voltage	$V_{ON(L)}$			0.5	V
Operating temperature	T_A	–40		+85	ºC

Table 4. AAT4616A Electrical Specifications (Note 1)
(V_{IN} = 5 V, T_A = –40 °C to +85 °C [Typical Values are at T_A = 25 °C], Unless Otherwise Noted)

Parameter	Symbol	Test Condition	Min	Typical	Max	Units
Input voltage	V_{IN}		2.4		5.5	V
Operating quiescent current	I_Q	V_{IN} = 5 V, ON/$\overline{ON}$ = Active, I_{OUT} = 0 A		10	25	µA
Off supply current	$I_{Q(OFF)}$	ON/$\overline{ON}$ = Inactive, V_{IN} = 5.5 V		0.01	1	µA
Off switch current	$I_{SD(OFF)}$	ON/$\overline{ON}$ = Inactive, V_{IN} = 5.5 V, V_{OUT} = 0 V		0.01	1	µA
Under-Voltage Lockout	V_{UVLO}	Rising edge, 1% Hysteresis		1.8	2.4	V
UVLO hysteresis	V_{UVLO_HYS}			10		mV
On resistance	$R_{DS(ON)}$	V_{IN} = 5.0 V, T_A = 25 °C		130	180	mΩ
		V_{IN} = 3.0 V, T_A = 25 °C		150	230	
On-resistance temperature coefficient	T_{CRDS}			2800		ppm/°C
Current limit	I_{LIM}	R_{SET} = 35 kΩ, V_{OUT} = V_{IN} – 0.5 V	0.67	0.75	0.83	A
Minimum current limit	$I_{LIM(MIN)}$			300		mA
ON/$\overline{ON}$ input low voltage	$V_{ON(L)}$	V_{IN} = 2.4 V to 5.5 V			0.5	V
ON/$\overline{ON}$ input high voltage	$V_{ON(H)}$	V_{IN} = 2.4 V to 5.5 V	1.4			V
ON/$\overline{ON}$ input leakage	$I_{ON(SINK)}$	V_{ON} = 5.5 V		0.01	1	µA
Current limit response time	t_{RESP}	V_{IN} = 5 V		2		µs
Turn-on time	t_{ON}	V_{IN} = 5 V, R_{LOAD} = 10 Ω		4	7	µs
Turn-off time	t_{OFF}	V_{IN} = 5 V, R_{LOAD} = 10 Ω	8	10		µs
Fault flag blanking time	t_{BLANK}			4		ms
Fault flag logic low output	$V_{FLT(L)}$	$I_{FLT(SINK)}$ = 1 mA			0.4	V
Fault flag logic high leakage current	$I_{FLT(SINK)}$			0.03	1	µA
Over-temperature shutdown threshold	T_{SD}	V_{IN} = 5 V		140		°C
Over-temperature shutdown hysteresis	T_{SD_HYS}			15		°C

Note 1: Performance is guaranteed only under the conditions listed in this Table.

Typical Performance Characteristics

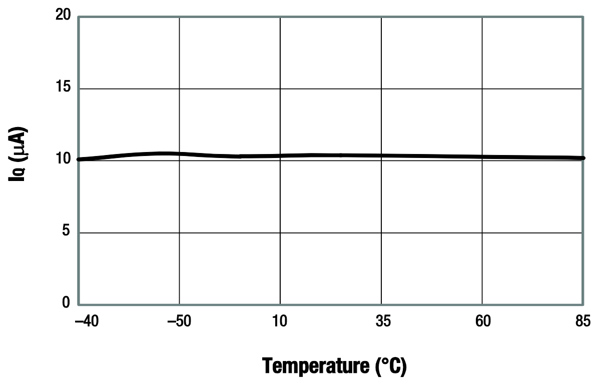


Figure 3. Quiescent Current vs Temperature (V_{IN} = 5.0 V)

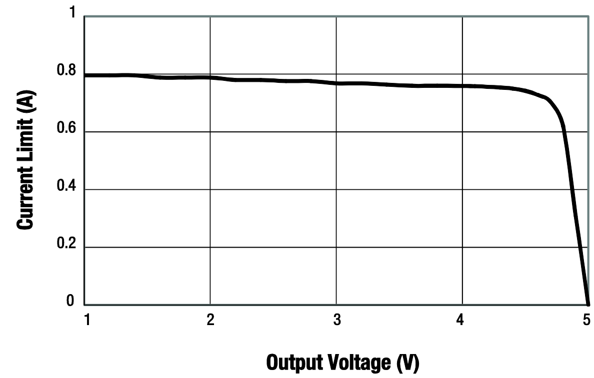


Figure 4. Current Limit vs Output Voltage (V_{IN} = 5.0 V, T_A = 25 °C, R_{SET} = 34.8 kΩ)

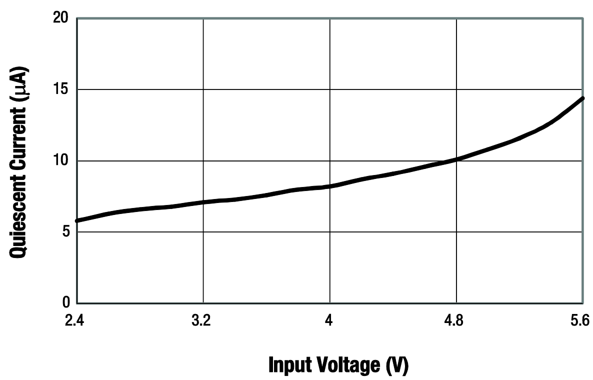


Figure 5. Quiescent Current Voltage (T_A = 25 °C)

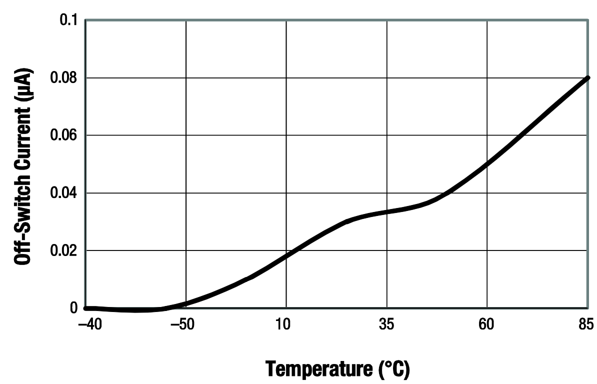


Figure 6. Off-Switch Current vs Temperature (V_{IN} = 5.0 V)

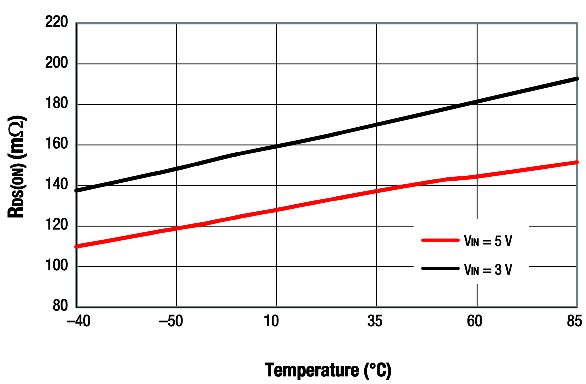


Figure 7. $R_{DS(ON)}$ vs Temperature

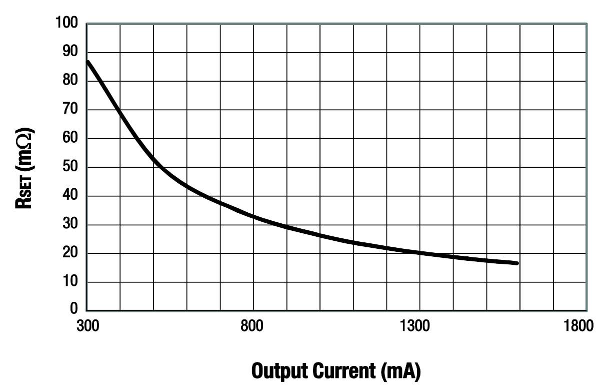


Figure 8. R_{SET} vs I_{LIM} (T_A = 25 °C)

Typical Performance Characteristics

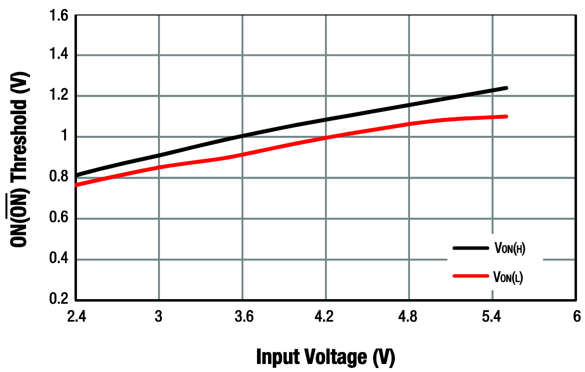


Figure 9. ON($\overline{ON}$) Threshold vs Input Voltage

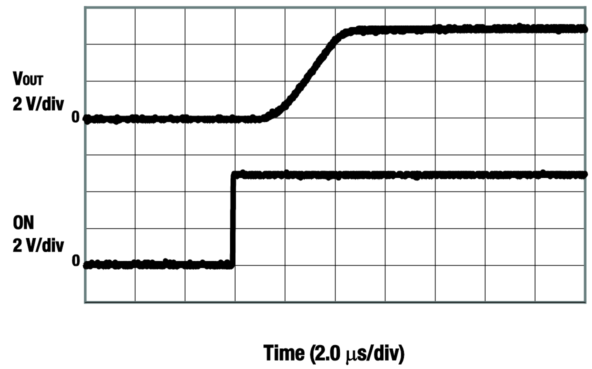


Figure 10. AAT4616AIPU-1 Turn-On
(R_L = 10 Ω, C_L = 0.47 µF)

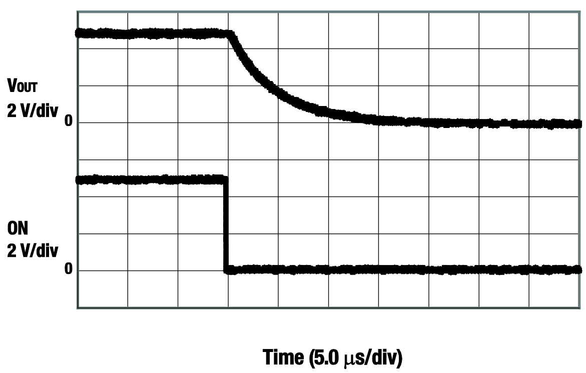


Figure 11. Figure 10. AAT4616AIPU-1 Turn-Off
(R_L = 10 Ω, C_L = 0.47 µF)

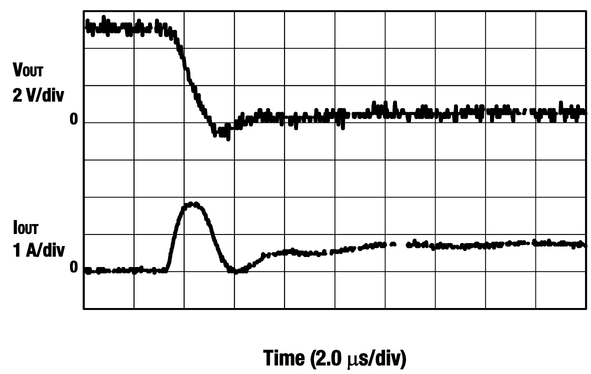


Figure 12. Short Circuit Through 0.3 Ω
(V_{IN} = 5.0 V)

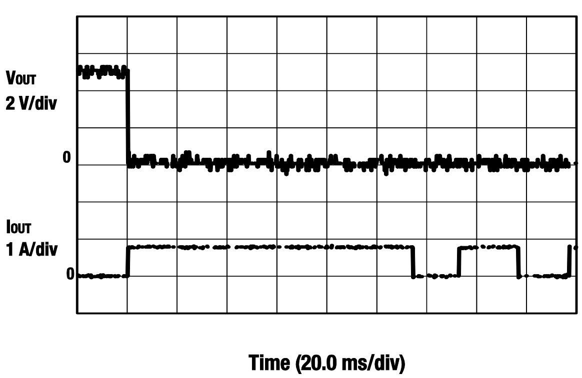


Figure 13. Output Short Response
(V_{IN} = 5.0 V)

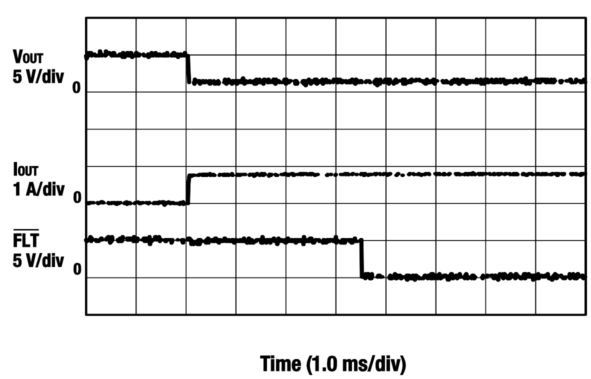


Figure 14. Fault Blanking Time
(V_{IN} = 5.0 V)

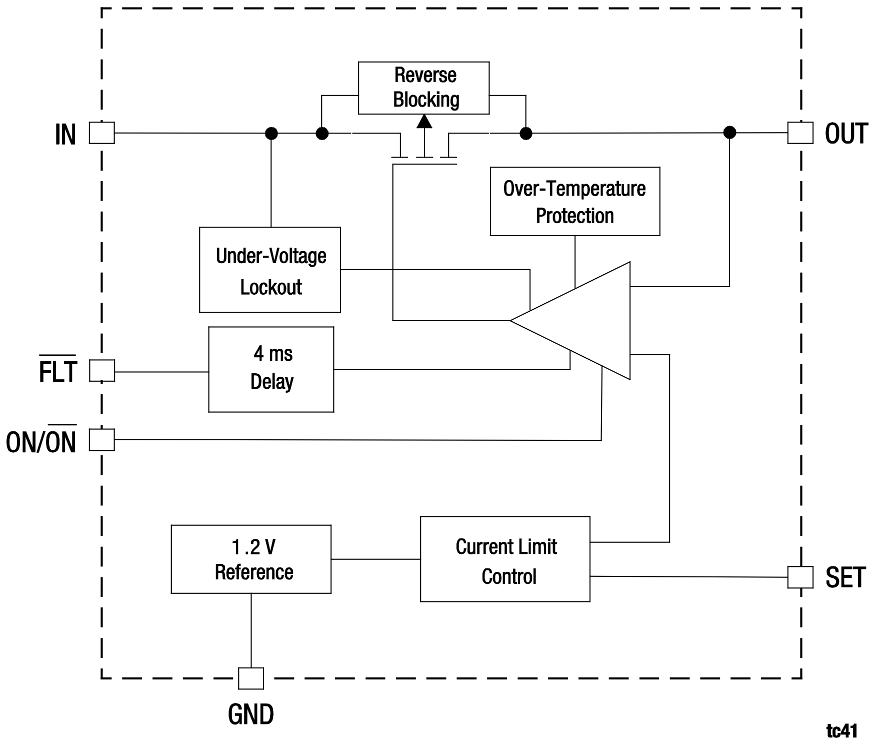


Figure 15. AAT4616A Functional Block Diagram

Functional Description

The AAT4616A is a single channel current limiting load switch that is intended to protect against short circuit and over-current events by current limiting to a preset level. This device also provides a reverse current blocking feature, on/off enable control, and a fault flag to notify a system controller of an over-current, short circuit or over-temperature event.

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

The AAT4616A is 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 to a level below the thermal limit threshold. This device may operate in a thermal cycling state indefinitely or until the over-current condition is removed.

The AAT4616A operates with input voltages ranging from 2.4 V to 5.5 V which, along with its extremely low operating current, make it ideal for battery-powered applications. In cases where the input voltage drops to below 2.4 V, the AAT4616A MOSFET is protected from entering the saturated region of operation by being automatically shut down by the UVLO circuit.

Current limit or over-temperature conditions are reported by the open drain FAULT output. A 4 ms blanking interval prevents false reporting during the charging of a capacitive load, which typically occurs during device turn-on, but may also occur during a port hot plug-in event. The AAT4616A is ideally suited for protection of peripheral ports such as USB, RS232, and parallel ports.

Reverse Current Blocking

The reverse current blocking feature prevents current flowing from OUT to IN when the device is disabled. When the device is enabled, the electrical characteristics between IN and OUT are still similar to an ideal switch, and current can flow in either direction.

Application Information

Setting Current Limit

The AAT4616A current limit can be set by an external resistor (R_{SET}) connected from the SET pin to GND. R_{SET} can be calculated by the following equation:

$$R_{SET} = \frac{750\ \text{mA}}{I_{LIM}} \times 35\ \text{k}\Omega$$

where I_{LIM} is in mA and R_{SET} in kΩ.

Table 5 summarizes resistor values for current limit settings. Use 1% tolerance metal film resistors to program the desired current limit setting. Figure 16 shows the output current versus output voltage with R_{SET} equal to 34.8 kΩ.

Table 5. Recommended 1% Tolerance Metal Film Resistors R_{SET} for Current Limit

R_{SET} (kΩ)	Current Limit (mA)
86.6	300
51	500
34.8	750
26.1	1000
21.5	1200
18.2	1400
16.5	1600

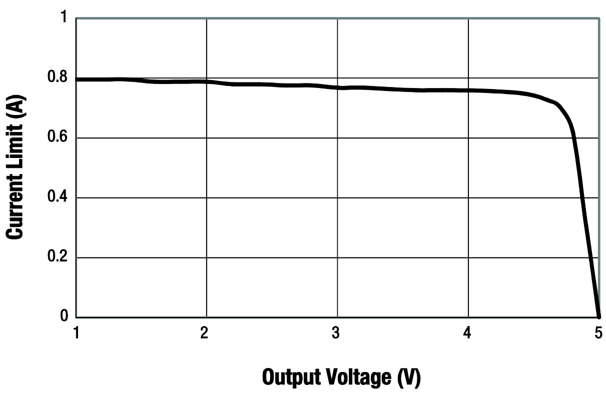


Figure 16. Current Limit vs Output Voltage with 34.8 kΩ R_{SET}

Input Capacitor

The input capacitor C_{IN} protects the power supply from current transients generated by the load attached to the AAT4616A. When a short circuit is suddenly applied to the output of the AAT4616A, a large current, limited only by the $R_{DS(ON)}$ of the MOSFET, flows for less than 1 μs before the current limit circuitry activates. In this event, a moderately sized C_{IN} dramatically reduces the voltage transient seen by the power supply and by other circuitry upstream from the AAT4616A.

The extremely fast short-circuit response time of the AAT4616A reduces the size requirement for C_{IN}. C_{IN} should be located as close to the device VIN pin as practically possible. Ceramic, tantalum, or aluminum electrolytic capacitors are appropriate for C_{IN}. There is no specific capacitor Equivalent Series Resistance (ESR) requirement for C_{IN}. 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

To ensure stability while the current limit is active, a low capacitance (approximately 0.47 μF) is required. No matter how large the output capacitor, the output current is limited to the value set by the AAT4616A current limiting circuitry, so very large output capacitors can be used.

For example, USB ports are specified to have at least 120 μF of capacitance downstream from their controlling power switch. The current limiting circuit allows an output capacitance of 1000 μF or more without disturbing the upstream power supply.

ON/$\overline{\text{ON}}$ (Enable Input)

In many systems, power planes are controlled by integrated circuits that run at lower voltages than the power planes, themselves. The enable input (ON/$\overline{\text{ON}}$) of the AAT4616A has low and high threshold voltages that accommodate this condition. The threshold voltages are compatible with 5 V TTL and 2.5 V ~ 5 V CMOS systems.

Both active high and active low options are available.

Connecting to Capacitive Load

When the AAT4616A is switched onto a capacitive load, the device charges the output capacitive load at a rate no greater than the current limit setting.

FAULT Output

The FAULT Flag $\overline{\text{FLT}}$ is provided to alert the system if an AAT4616A 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 4 ms, the FAULT Flag is pulled to ground through an approximately 100 Ω resistor.

The filtering of voltage or current transients of less than 4 ms prevents capacitive loads connected to the AAT4616A output from activating the FAULT Flag when they are initially attached. Pull-up resistances of 10 kΩ to 100 kΩ are recommended. Since $\overline{\text{FLT}}$ is an open-drain terminal; it may be pulled up to any unrelated voltage less than the maximum operating voltage of 5.5 V, allowing for level shifting between circuits.

Thermal Considerations

Since the AAT4616A has 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, is 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 the current limit is inactive can be calculated using the following equation:

$$T_{J(MAX)} = I^2_{MAX(OUT)\_SW(MAX)} \times R_{DS(ON)(MAX)} \times R_{\theta JA} + T_{A(MAX)} \qquad (1)$$

Where:

I_{MAX} is the maximum current required by the load.

$R_{DS(ON)(MAX)}$ is the maximum rated $R_{DS(ON)}$ of the AAT4616A at high temperature.

$R_{\theta JA}$ is the thermal resistance between the AAT4616A die and the board onto which it is mounted.

$T_{A(MAX)}$ is the maximum temperature that the PCB under the AAT4616A would be if the AAT4616A were not dissipating power.

Rearranging equation (1) to solve for I_{MAX}:

$$I_{MAX} = \sqrt{\frac{T_{SD(MIN)} - T_{A(MAX)}}{R_{DS(ON)} \times R_{\theta JA}}} \qquad (2)$$

Note that $T_{J(MAX)}$ has been replaced by $T_{SD(MIN)}$, the minimum temperature required to activate the over-temperature protection feature of the AAT4616A. With the typical specification of 140 °C, a safe minimum value to use would be 125 °C.

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 85 °C/W. Using equation (2):

$$I_{MAX} = \sqrt{\frac{125 - 85}{0.23 \times 85}}$$

Evaluation Board Information

The AAT4616A Evaluation Board schematic diagram is provided in Figure 17. The PCB layer details are shown in Figure 18, and Table 6 lists the Evaluation Board Bill of Materials (BOM).

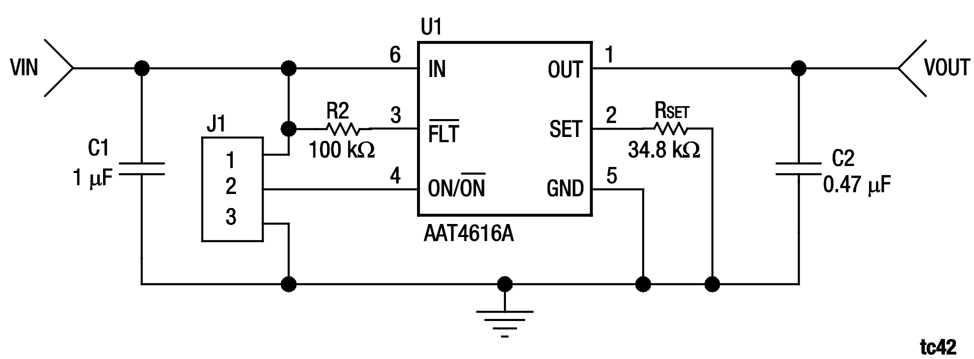
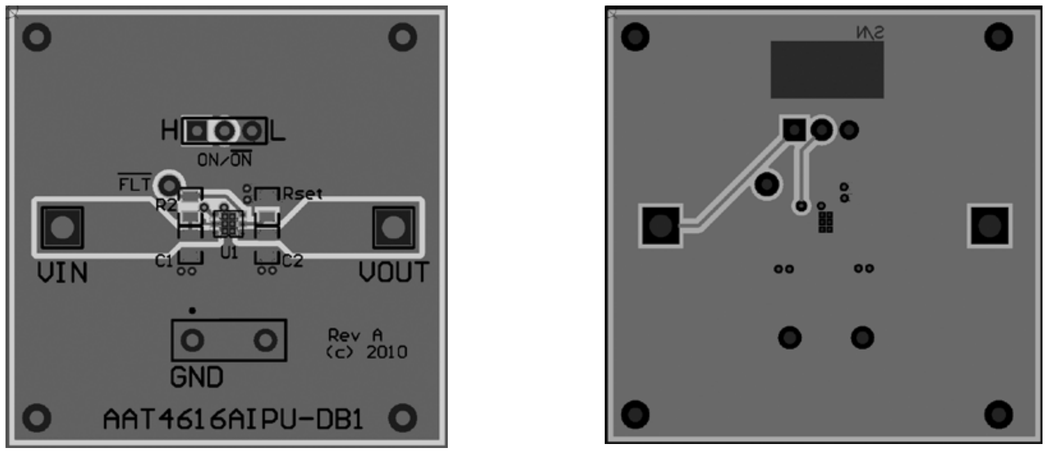


Figure 17. AAT4616A Evaluation Board Schematic

Table 6. AAT4616A Evaluation Board Bill of Materials (BOM)

Component	Part Number	Description	Manufacturer
U1	AAT4616AIPU-T1	Current Limited Load Switch	Skyworks
C1	GRM188R71C105K	Ceramic capacitor, 1 μF, 0603 X7R, 16 V, 10%	Murata
C2	GRM188R71C474K	Ceramic capacitor, 0.47 μF, 0603 X7R, 16 V, 10%	Murata
RSET	Chip Resistor	Resistor, 34.8 kΩ, 1/16 W, 1%, 0603 SMD	Vishay
R2	Chip Resistor	Resistor, 100 kΩ, 1/16 W, 1%, 0603 SMD	Vishay



(a) Top layer

(a) Top layer

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Figure 18. AAT4616A Evaluation Board Layer Details

Package Information

Package dimensions for the TDFN22-6 are shown in Figure 19, and tape and reel dimensions are provided in Figure 20.

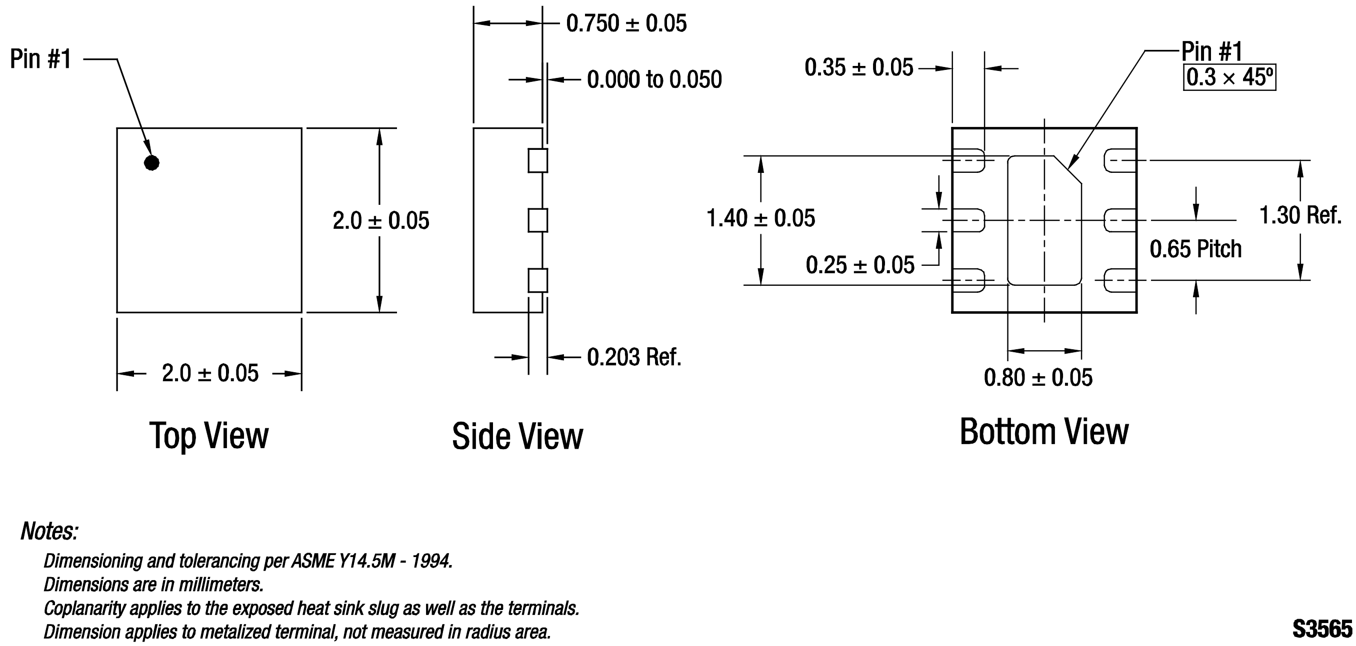

Figure 19. AAT4616A TDFN22-6 Package Dimensions

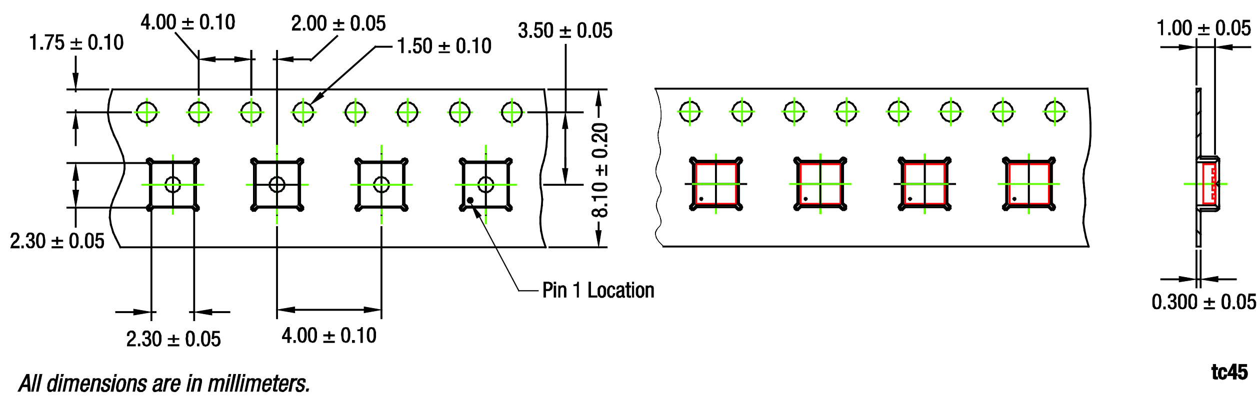

Figure 20. AAT4616A Tape and Reel Dimensions

Ordering Information

Model Name	Enable Input	Package	Marking (Note 1)	Manufacturing Part Number (Note 2)	Evaluation Board Part Number
AAT4616A Adjustable Current Limited Load Switch with Fault Flag	Active High	TDFN22-6	R9XYY	**AAT4616AIPU-1-T1**	AAT4616AIPU-1-EVB
	Active Low	TDFN22-6	U4WBF	AAT4616AIPU-T1	AAT4616AIPU-EVB

Note 1: XYY = assembly and date code.

Note 2: Sample stock is generally held on part numbers listed in **BOLD**.

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- Техническая поддержка проекта;
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