DATA SHEET

AAT4616: Ultrahigh 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
- ±5% 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 masking at startup (capacitive load)
- Fault flag open-drain output
- Active High/Low enable options
- Over-temperature protection
- Temperature range: –40 °C to +85 °C
- 5-pin SOT23-5 and 8-pin TDFN package (MSL1, 260 °C per JEDEC-J-STD-020)

Description

The AAT4616 SmartSwitch is a current-limit 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, highly accurate current-limit 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 flows while the device is in shutdown.

The AAT4616 is also protected from thermal overload, which limits power dissipation and junction temperature. Current-limit threshold is programmed with a resistor from SET to ground, and is adjusted for load levels up to 1.6 A. The ultrafast current limit response to a sudden short circuit is 2 μs, which reduces the requirements of local supply bypassing. An open-drain FAULT flag signals an over-current or over-temperature condition. To prevent false reporting, a 4 ms time interval is used at startup (charging a capacitive load), where fault conditions are not monitored and reported. Quiescent current is a low 10 μA and the supply current decreases to less than 1 μA in shutdown mode.

The AAT4616 is offered in small Pb-free, 5-pin SOT23-5 and TDFN22-8 packages, and is specified for operation over the –40°C to +85°C ambient temperature range.

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.

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.

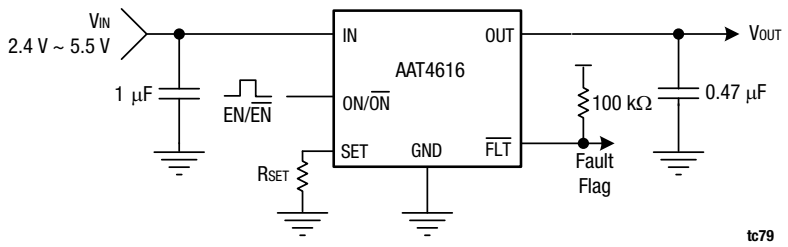


Figure 1. AAT4616 Typical Application Circuit

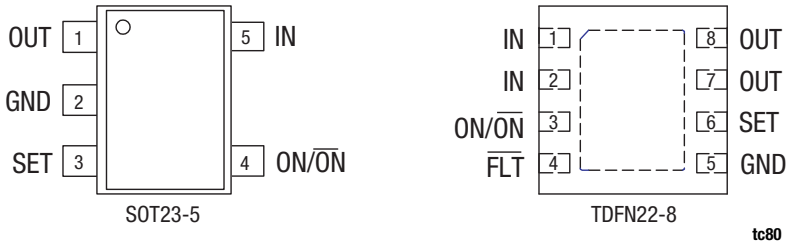


Figure 2. AAT4616 Pinout – 5-Pin SOT23 and 8-Pin TDFN (Top View)

Table 1. AAT4616 Signal Descriptions

Pin #		Name	Description
SOT23-5	*TDFN22-8*		
1	7, 8	OUT	Current-limit 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	5	GND	IC ground connection.
3	6	SET	Current-limit set pin. Connect a resistor between this pin and ground to program the desired current limit set point.
4	3	ON/$\overline{ON}$	Load switch enable input. Active high and active low options are available.
5	1, 2	IN	Load switch power supply input pin (high-side P-channel MOSFET source). Bypass with a 1 µF capacitor from IN to GND.
NA	4	$\overline{FLT}$	Current-limit fault flag pin, open-drain output, active low signal. Pull up with a 10 kΩ to 100 kΩ resistor.

Electrical and Mechanical Specifications

The absolute maximum ratings of the AAT4616 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 AAT4616 are illustrated in Figures 3 through 14.

Table 2. AAT4616 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	ºC
Storage temperature range	T_{STG}		–40		+150	ºC
Maximum soldering temperature (at leads)	T_{LEAD}			300		ºC
Thermal resistance	θ_{JA}	TDFN22-8		74		ºC/W
		SOT23-5		220		ºC/W
Power dissipation (Notes 3 and 4)	P_D	TDFN22-8		1.35		W
		SOT23-5		0.45		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.

Note 4: Derated 13.5 mW/ºC for TDFN22-8 package and 4.5 mW/ºC for SOT23-5 package above 25 ºC.

***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.*

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. AAT4616 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
Operation 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
Under-voltage lockout 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	mΩ
On-resistance temperature coefficient	T_{CRDS}			2800		ppm/°C
Current limit	I_{LIM}	R_{SET} = 6.04 kΩ, V_{OUT} = V_{IN} – 0.5 V	0.71	0.75	0.79	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		5	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

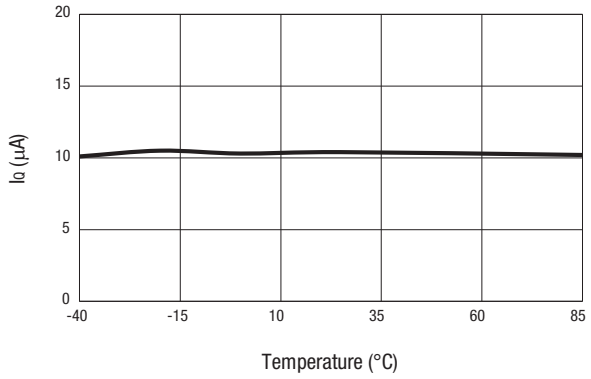


Figure 3. Quiescent Current vs Temperature (V_{IN} = 5.0 V)

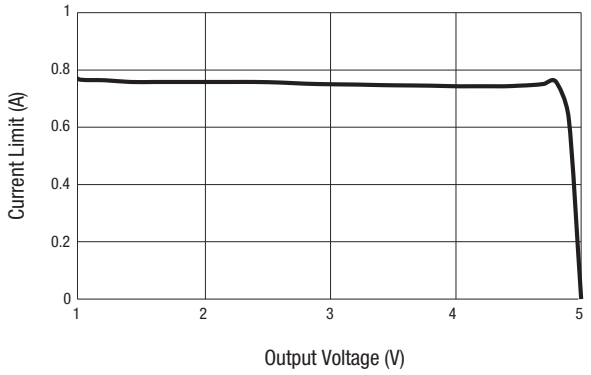


Figure 4. Current Limit vs Output Voltage (V_{IN} = 5.0 V, T_A = 25 °C, R_{SET} = 6.04 kΩ)

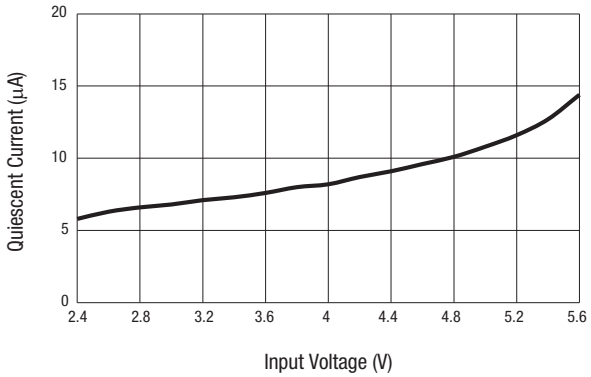


Figure 5. Quiescent Current vs Input Voltage (T_A = 25 °C)

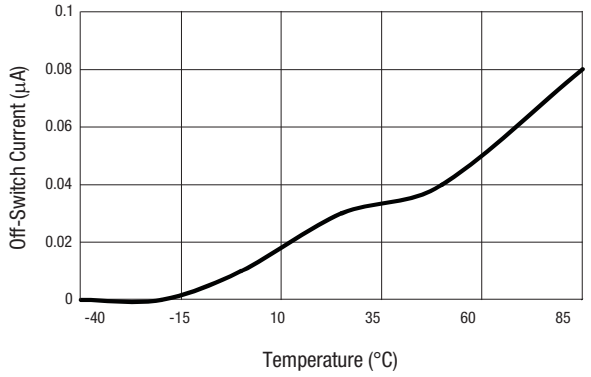


Figure 6. Off-Switch Current vs Temperature (V_{IN} = 5.5 V)

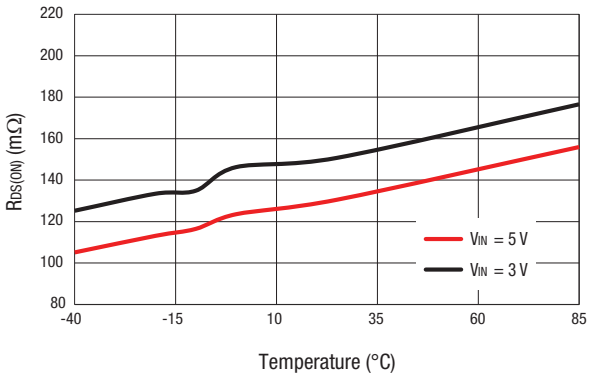


Figure 7. $R_{DS(ON)}$ vs Temperature

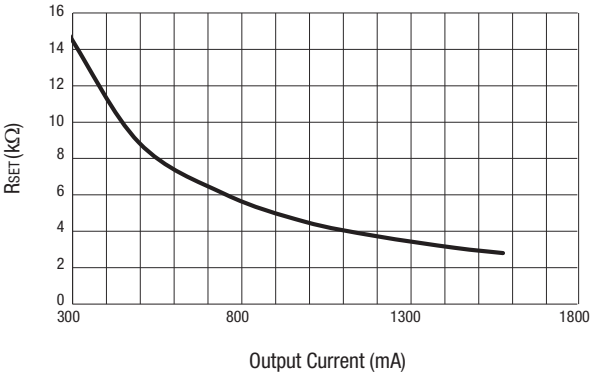


Figure 8. R_{SET} vs I_{LIM} (T_A = 25 °C)

Typical Performance Characteristics

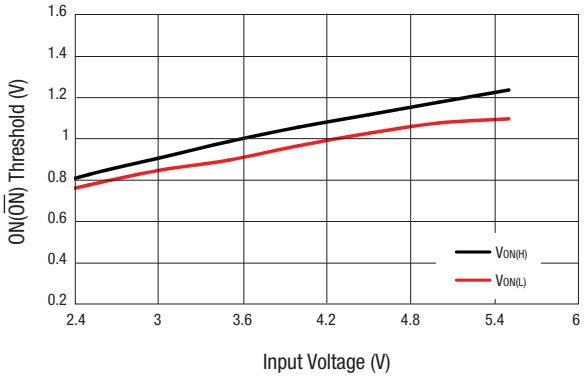


Figure 9. ON($\overline{ON}$) Threshold vs Input Voltage

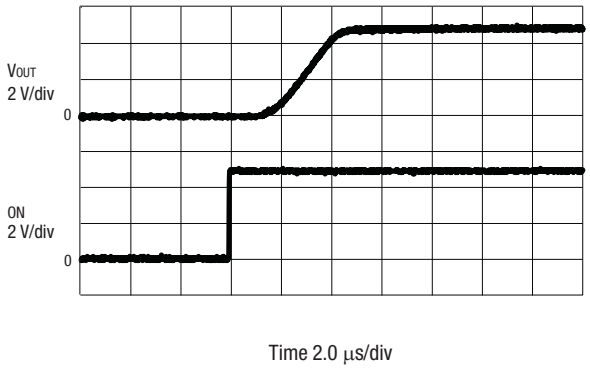


Figure 10. AAT4616IPS-1 and AAT4616IGV-1 Turn-On (R_L = 10 Ω, C_L = 0.47 µF)

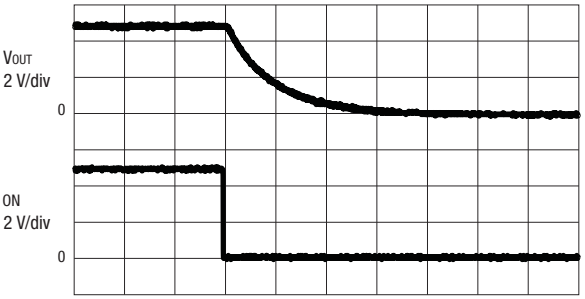


Figure 11. AAT4616IPS-1 and AAT4616IGV-1 Turn-Off (R_L = 10 Ω, C_L = 0.47 µF)

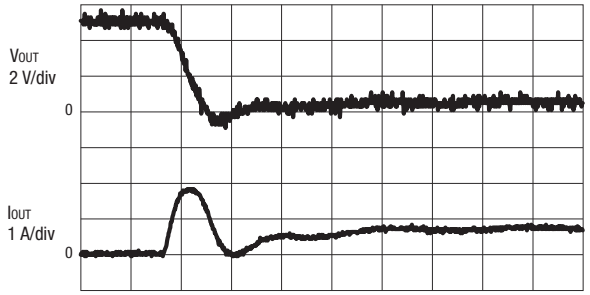


Figure 12. Short Circuit Through 0.3 Ω (V_{IN} = 5.0 V)

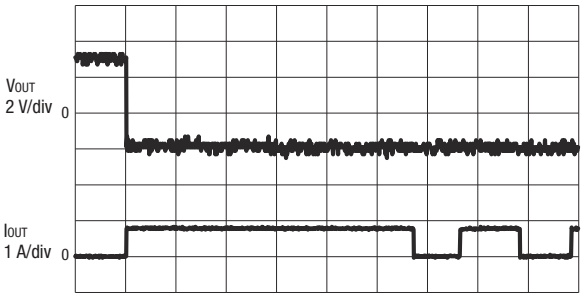


Figure 13. Output Short Response (V_{IN} = 5.0 V)

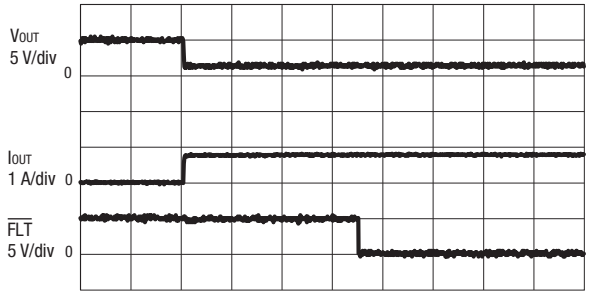


Figure 14. Fault Blanking Time (V_{IN} = 5.0 V)

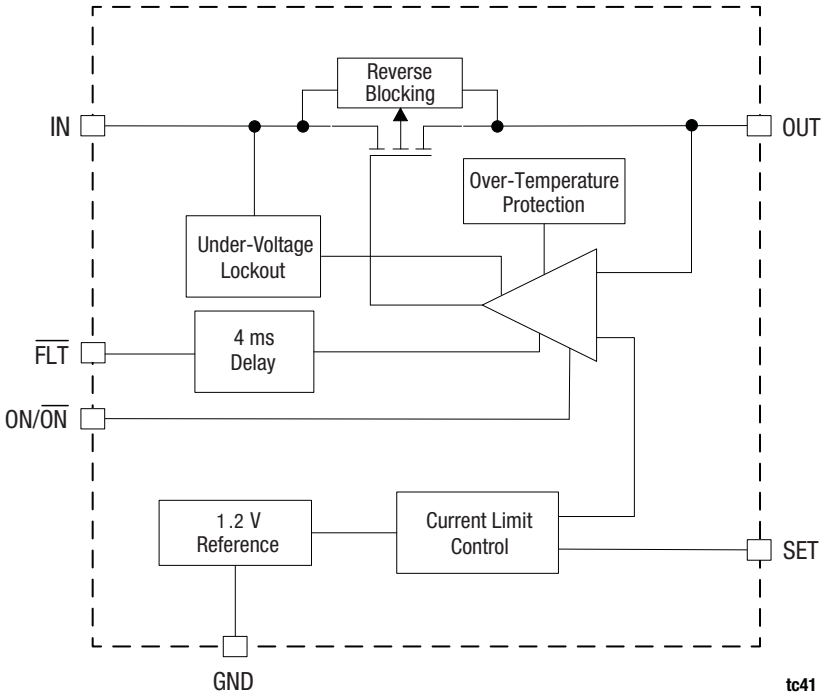


Figure 15. AAT4616 Functional Block Diagram

Functional Description

The AAT4616 is a single-channel current-limit 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 events.

In the event of a load current exceeding a 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 AAT4616 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 AAT4616 operates with input voltages ranging from 2.4 V to 5.5 V which, along with its extremely low operating current, makes it ideal for battery-powered applications. In cases where the input voltage drops below 2.4 V, the AAT4616 MOSFET is protected from entering the saturated region of operation by being automatically shut down by the under-voltage lockout circuit.

Current limit or over-temperature conditions are reported by the open drain FAULT output. A 4 ms masking 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 AAT4616 is ideally suited for protection of peripheral ports such as USB, RS232, and parallel ports.

Figure 15 shows the functional block diagram.

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 is still similar to an ideal switch, and current can flow in either direction.

Application Information

Setting Current Limit

The AAT4616 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:

$$R_{SET} = \frac{750mA}{I_{LIM}} \times 6k\Omega$$

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 for programming the desired current limit setting. Figure 16 shows the output current vs. output voltage with R_{SET} equal to 6.04 kΩ.

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

R_{SET} (kΩ)	Current Limit (mA)
15	300
8.87	500
6.04	750
4.53	1000
3.74	1200
3.09	1400
2.8	1600

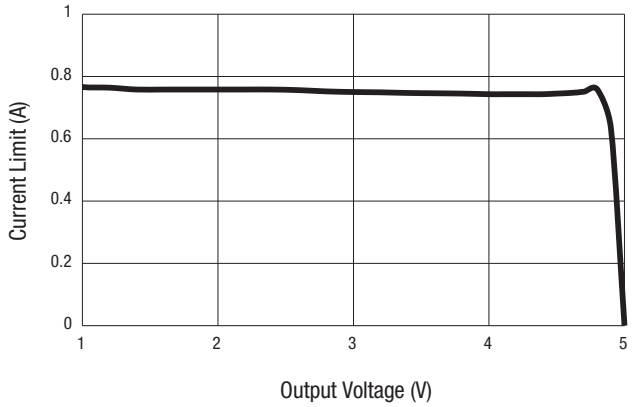


Figure 16. Current Limit vs Output Voltage (V_{IN} = 5.0 V, T_A = 25 °C, R_{SET} = 6.04 kΩ)

Input Capacitor

The input capacitor C_{IN} protects the power supply from current transients generated by the load attached to the AAT4616. When a short circuit is suddenly applied to the output of the AAT4616, 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 AAT4616.

The extremely fast short-circuit response time of the AAT4616 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

In order to ensure stability while 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 AAT4616 current-limit 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/$\overline{ON}$ (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/$\overline{ON}$) of the AAT4616 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 for all packages.

Connecting to Capacitive Load

When switching the AAT4616 onto a capacitive load, the AAT4616 charges 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 AAT4616 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 AAT4616 output from activating the FAULT Flag when they are initially attached. Pull-up resistances of 10 kΩ to 100 kΩ are recommended. Since $\overline{FLT}$ 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 AAT4616 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 current limit is not active can be calculated using the following equation:

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

where:

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

$R_{DS(ON)(MAX)}$ is the maximum rated $R_{DS(ON)}$ of the AAT4616 at high temperature.

$R_{\theta JA}$ is the thermal resistance between the AAT4616 die and the board onto which it is mounted.

$T_{A(MAX)}$ is the maximum temperature that the PCB under the AAT4616 would be if the AAT4616 were not dissipating power.

Rearranging the equation to solve for I_{MAX}:

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

Note that $T_{J(MAX)}$ has been replaced by $T_{SD(MIN)}$, the minimum temperature required to activate the AAT4616's over-temperature protection. With the typical specification of 140 °C, 125 °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 74 °C/W (TDFN22-8 package) and 220 °C/W (SOT23-5 package). Using equation (2):

$$I_{MAX} = \sqrt{\frac{125 - 85}{0.23 \times 74}} \qquad \text{for TDFN22-8}$$

or

$$I_{MAX} = \sqrt{\frac{125 - 85}{0.23 \times 220}} \qquad \text{for SOT23-5}$$

Evaluation Board Information

The AAT4616IPS evaluation board schematic diagram is provided in Figure 17, and the PCB layer details are shown in Figure 18.

The AAT4616IGV evaluation board schematic diagram is provided in Figure 19, and the PCB layer details are shown in Figure 20. Table 6 lists the AAT4616 evaluation board bill of materials.

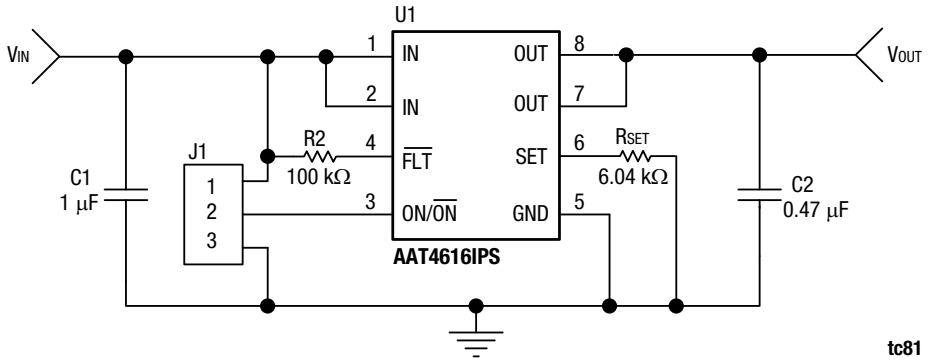


Figure 17. AAT4616IPS Evaluation Board Schematic

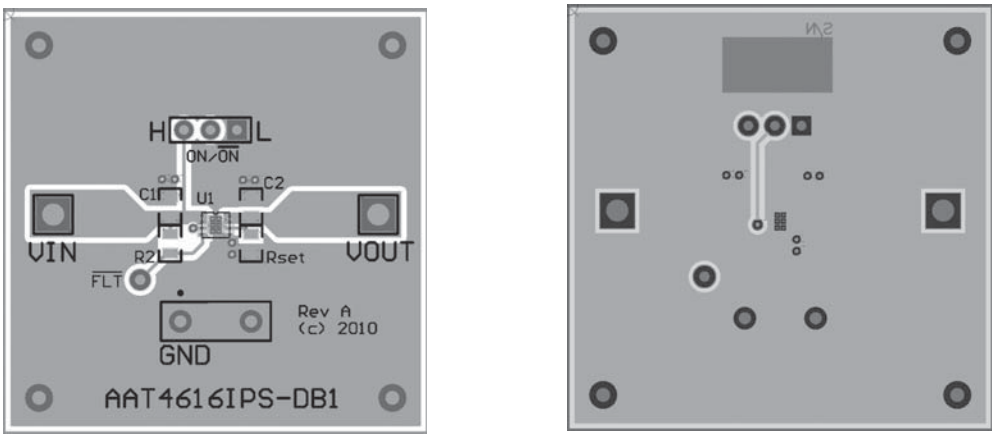


Figure 18. AAT4616IPS Evaluation Board Layer Details

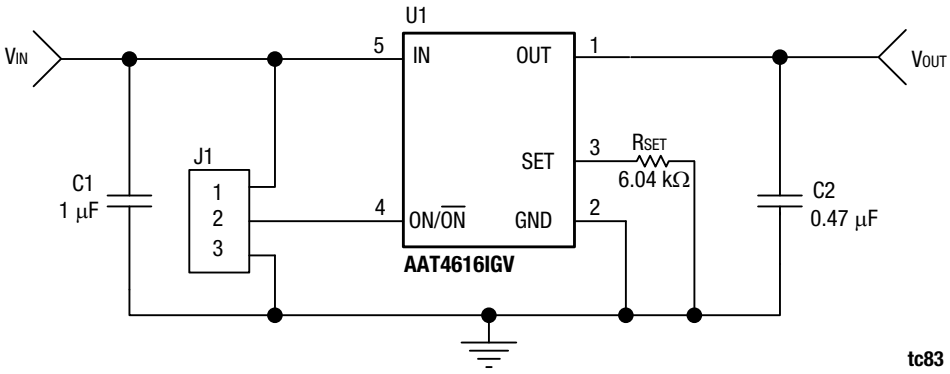


Figure 19. AAT4616IGV Evaluation Board Schematic

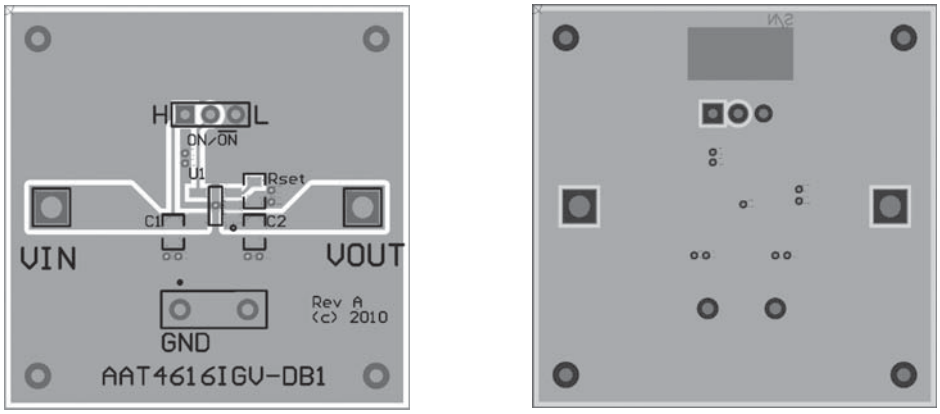


Figure 20. AAT4616IGV Evaluation Board Layer Details

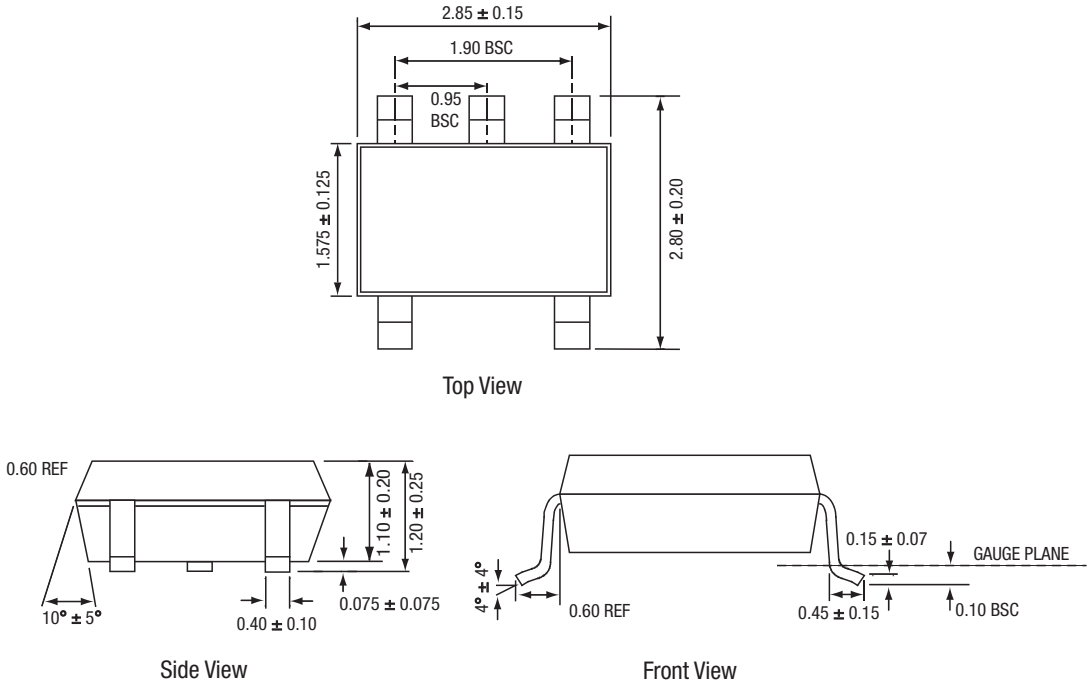
Table 6. AAT4616 Evaluation Board Bill of Materials

Component	Part Number	Description	Manufacturer
U1	AAT4616	Current limited load switch	Skyworks
C1	GRM188R71C105K	Capacitor ceramic, 1 µF, 0603 X7R, 16 V, 10%	Murata
C2	GRM188R71C474K	Capacitor ceramic, 0.47 µF, 0603 X7R, 16 V, 10%	Murata
Rset	Chip Resistor	Resistor, 6.04 kΩ, 1/16 W, 1%, 0603 SMD	Vishay
R2	Chip Resistor	Resistor, 100 kΩ, 1/16 W, 1%, 0603 SMD	Vishay

Package Information

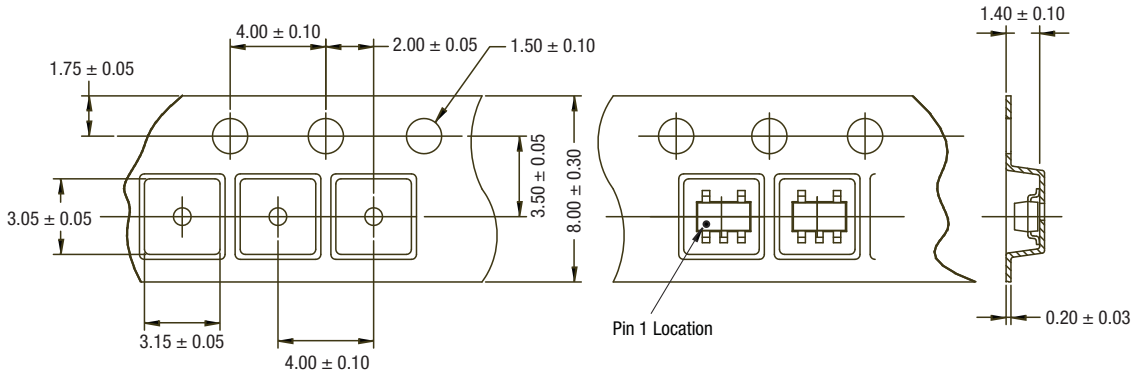
Package dimensions for the SOT23-5 are shown in Figure 19, and tape and reel dimensions are provided in Figure 20.

Package dimensions for the TDFN22-8 are shown in Figure 21, and tape and reel dimensions are provided in Figure 22.



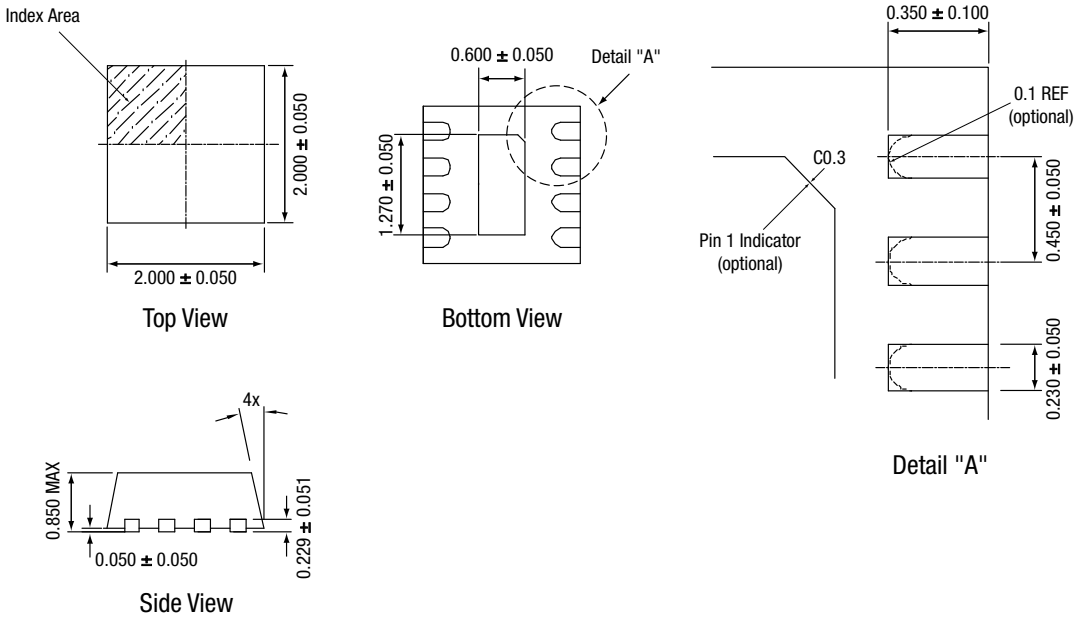
All dimensions are in millimeters. tc12

Figure 19. AAT4616 SOT23-5 Package Dimensions



All dimensions are in millimeters. tc85

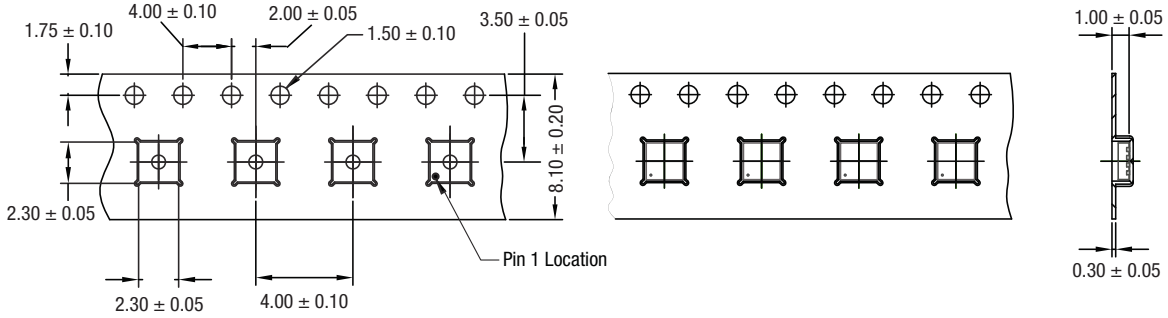
Figure 20. AAT4616 Tape and Reel Dimensions (SOT23-5)



All dimensions are in millimeters.

tc86

Figure 21. AAT4616 TDFN22-8 Package Dimensions



All dimensions are in millimeters.

tc45

Figure 22. AAT4616 Tape and Reel Dimensions (TDFN22-8)

Ordering Information

Model Name	Enable Input	Package	Marking (Note 1)	Manufacturing Part Number (Note 2)	Evaluation Board Part Number
AAT4616 ultra high precision adjustable current limited load switch with fault flag	Active High	TDFN22-8	R8XYY	**AAT4616IPS-1-T1**	AAT4616IPS-1-EVB
	Active Low	TDFN22-8	U6VBF	**AAT4616IPS-T1**	AAT4616IPS-EVB
	Active High	SOT23-5	R7XYY	**AAT4616IGV-1-T1**	AAT4616IGV-1-EVB
	Active Low	SOT23-5	U5IBF	**AAT4616IGV-T1**	AAT4616IGV-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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