

General Description

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

The AAT4616A is offered in the small Pb-free, TDFN22-6 package, and is specified for operation over the -40°C to +85°C ambient temperature range

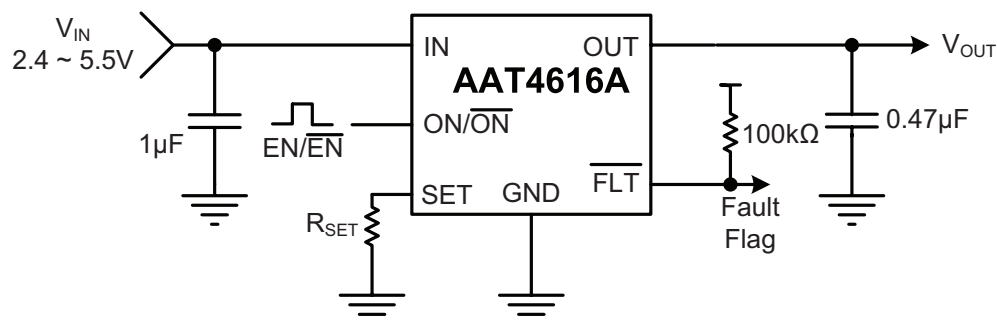
Features

- Input Voltage Range: 2.4V to 5.5V
- Programmable Over-Current Limit Setting:
 - 300mA to 1.6A
- $\pm 10\%$ Current Limit Precision at 750mA
- Fast Transient Response:
 - 2 μ s Response to Short Circuit
- Low Quiescent Current
 - 10 μ A Typical while Enabled
 - 1 μ A Max with Switch Off
- 130m Ω Typical $R_{DS(ON)}$
- Under-Voltage Lockout (UVLO)
- Reverse Blocking During Disable
- 4ms Fault Blanking
- Fault Flag Open Drain Output
- Active Hi/Lo Enable Options
- Over Temperature Protection
- TDFN22-6 Package
- Temperature Range: -40°C to +85°

Applications

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

Typical Application

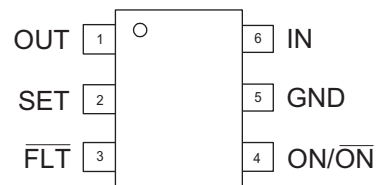


Pin Descriptions

Pin #	Symbol	Function
1	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.
2	SET	Current limit set pin. Connect a resistor between this pin and ground to program the desired current limit set point.
3	$\overline{\text{FLT}}$	Current limit fault flag pin, open-drain output, active low signal. Pull up with a 10kΩ to 100kΩ resistor.
4	ON/ $\overline{\text{ON}}$	Load switch enable input. Active high and active low options are available.
5	GND	IC Ground Connection
6	IN	Load Switch Power Supply Input pin (high side P-channel MOSFET source). Bypass with a 1µF capacitor from IN to GND.

Pin Configuration

**TDFN22-6
(Top View)**



Absolute Maximum Ratings¹

Symbol	Description	Value	Units
V_{IN}	IN to GND	-0.3 to 6	V
V_{ON}, V_{FLT}	ON/ \overline{ON} , \overline{FLT} to GND	-0.3 to $V_{IN} + 0.3$	
V_{SET}, V_{OUT}	SET, OUT to GND	-0.3 to $V_{IN} + 0.3$	
I_{MAX}	Maximum DC Output Current ²	2	A
T_J	Operating Junction Temperature Range	-40 to 150	°C
T_{STG}	Storage Temperature Range	-40 to 150	
T_{LEAD}	Maximum Soldering Temperature (at leads)	300	

Thermal Characteristics

Symbol	Description	Value	Units
Θ_{JA}	Thermal Resistance	85	°C/W
P_D	Power Dissipation ^{3,4}	1.18	W

Recommended Operating Conditions

Symbol	Description	Min	Max	Unit
V_{IN}	Input Voltage	2.4	5.5	V
$V_{ON(H)}$	High-level Input Voltage	1.4		
$V_{ON(L)}$	Low-level Input Voltage		0.5	
T_A	Operating Temperature	-40	+85	°C

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

3. Mounted on an FR4 board.

4. Derated 11.8 mW/°C above 25°C

Electrical Characteristics

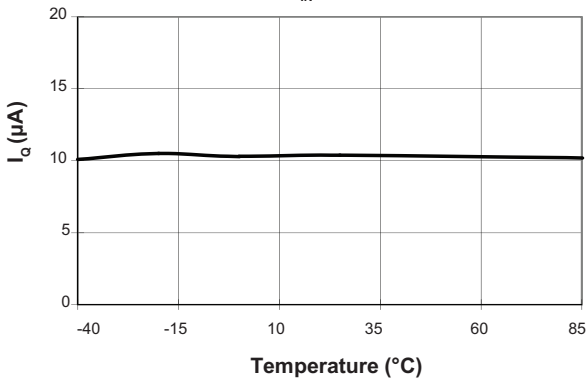
$V_{IN} = 5V$, $T_A = -40^{\circ}C$ to $+85^{\circ}C$, unless otherwise noted. Typical values are at $T_A = 25^{\circ}C$.

Symbol	Description	Conditions	Min	Typ	Max	Units
V_{IN}	Input Voltage Range		2.4		5.5	V
I_Q	Operation Quiescent Current	$V_{IN} = 5V$, $ON/\overline{ON} = \text{Active}$, $I_{OUT} = 0$		10	25	μA
$I_{Q(OFF)}$	Off Supply Current	$ON/\overline{ON} = \text{Inactive}$, $V_{IN} = 5.5V$		0.01	1	
$I_{SD(OFF)}$	Off Switch Current	$ON/\overline{ON} = \text{Inactive}$, $V_{IN} = 5.5V$, $V_{OUT} = 0$		0.01	1	
V_{UVLO}	Under-Voltage Lockout	Rising Edge, 1% Hysteresis		1.8	2.4	V
V_{UVLO_HYS}	Under-voltage Lockout Hysteresis			10		mV
$R_{DS(ON)}$	On Resistance	$V_{IN} = 5.0V$, $T_A = 25^{\circ}C$		130	180	m Ω
		$V_{IN} = 3.0V$, $T_A = 25^{\circ}C$		150	230	
T_{CRDS}	On-Resistance Temperature Coefficient			2800		ppm/ $^{\circ}C$
I_{LIM}	Current Limit	$R_{SET} = 35k\Omega$, $V_{OUT} = V_{IN} - 0.5V$	0.67	0.75	0.83	A
$I_{LIM(MIN)}$	Minimum Current Limit			300		mA
$V_{ON(L)}$	ON/\overline{ON} Input Low Voltage	$V_{IN} = 2.4V$ to $5.5V$			0.5	V
$V_{ON(H)}$	ON/\overline{ON} Input High Voltage	$V_{IN} = 2.4V$ to $5.5V$	1.4			
$I_{ON(SINK)}$	ON/\overline{ON} Input Leakage	$V_{ON} = 5.5V$		0.01	1	μA
T_{RESP}	Current Limit Response Time	$V_{IN} = 5V$		2		μs
T_{ON}	Turn-On Time	$V_{IN} = 5V$, $R_O = 10\Omega$		5	200	
T_{OFF}	Turn-Off Time	$V_{IN} = 5V$, $R_O = 10\Omega$		10	100	
T_{BLANK}	Fault Flag Blanking Time			4		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			0.03	1	μA
T_{SD}	Over-Temperature Shutdown Threshold	$V_{IN} = 5V$		140		$^{\circ}C$
T_{SD_HYS}	Over-Temperature Shutdown Hysteresis			15		$^{\circ}C$

Typical Characteristics

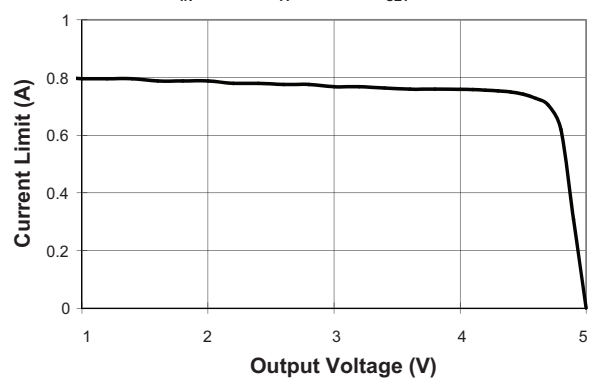
Quiescent Current vs Temperature

$V_{IN} = 5V$



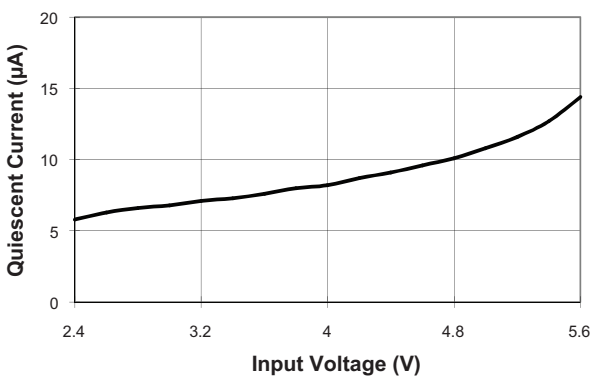
Current Limit vs Output Voltage

$V_{IN} = 5.0V, T_A = 25^\circ C, R_{SET} = 34.8k\Omega$



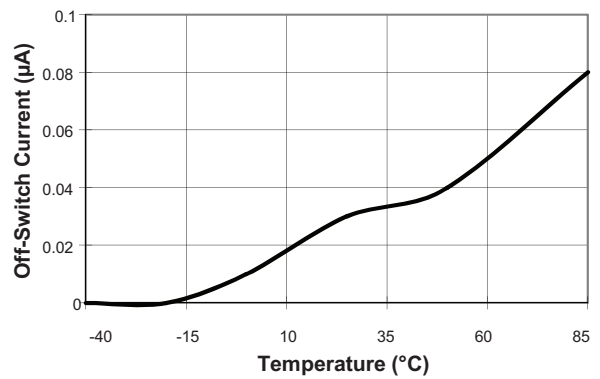
Quiescent Current vs Input Voltage

$T_A = 25^\circ C$

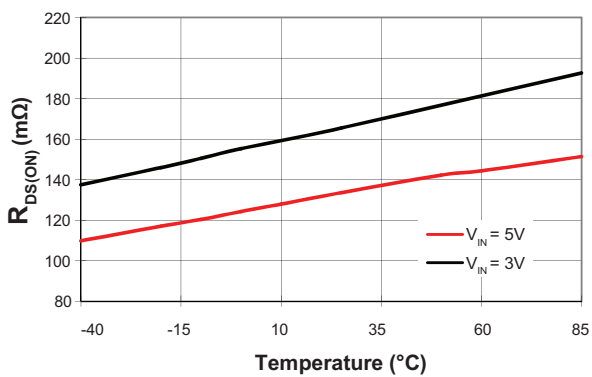


Off-Switch Current vs Temperature

$V_{IN} = 5.5V$

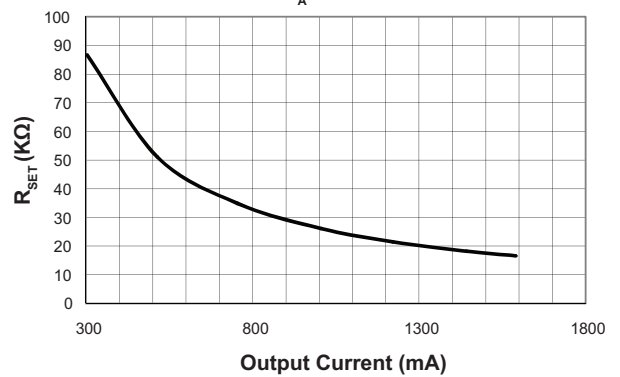


$R_{DS(ON)}$ vs Temperature



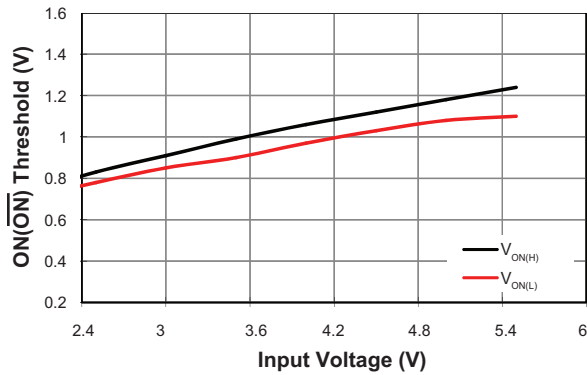
R_{SET} vs I_{LIM}

$T_A = 25^\circ C$

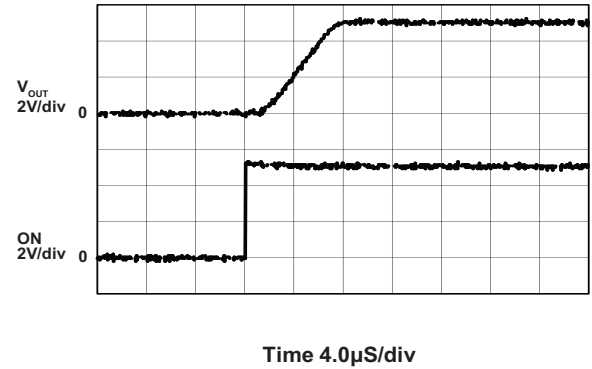


Typical Characteristics

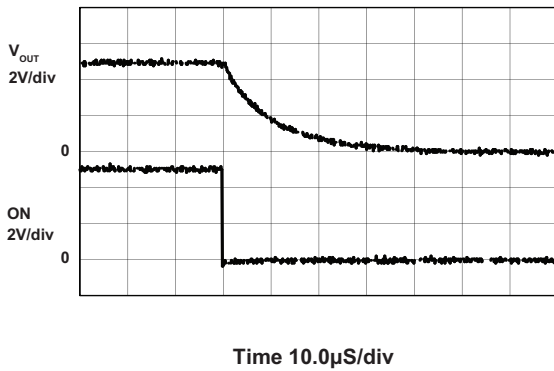
ON($\overline{\text{ON}}$) Threshold vs Input Voltage



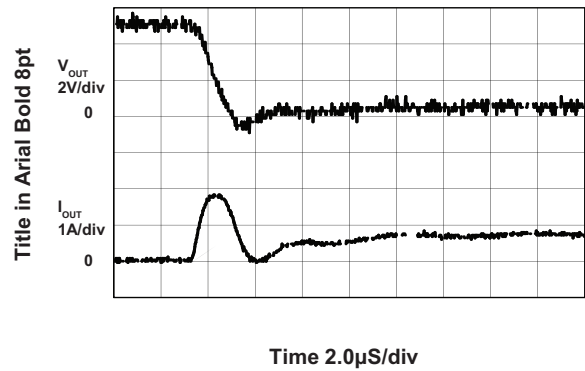
AAT4616AIPU-1 Turn-On
($R_L = 10\Omega$; $C_L = 0.47\mu\text{F}$)



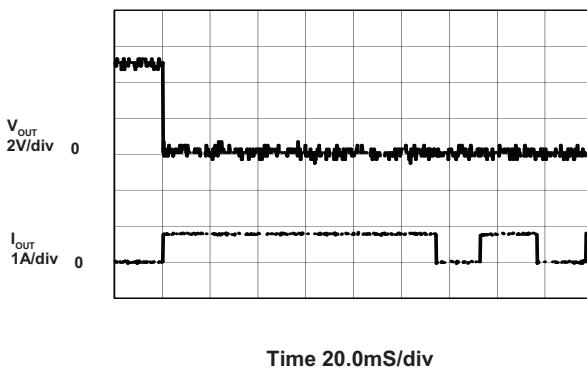
AAT4616AIPU-1 Turn-Off
($R_L = 10\Omega$; $C_L = 0.47\mu\text{F}$)



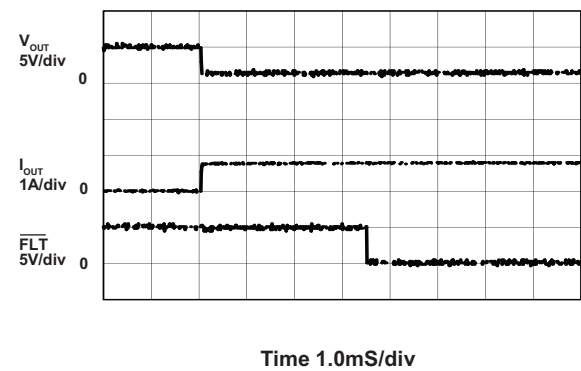
Short Circuit Through 0.3Ω
 $V_{\text{IN}} = 5\text{V}$



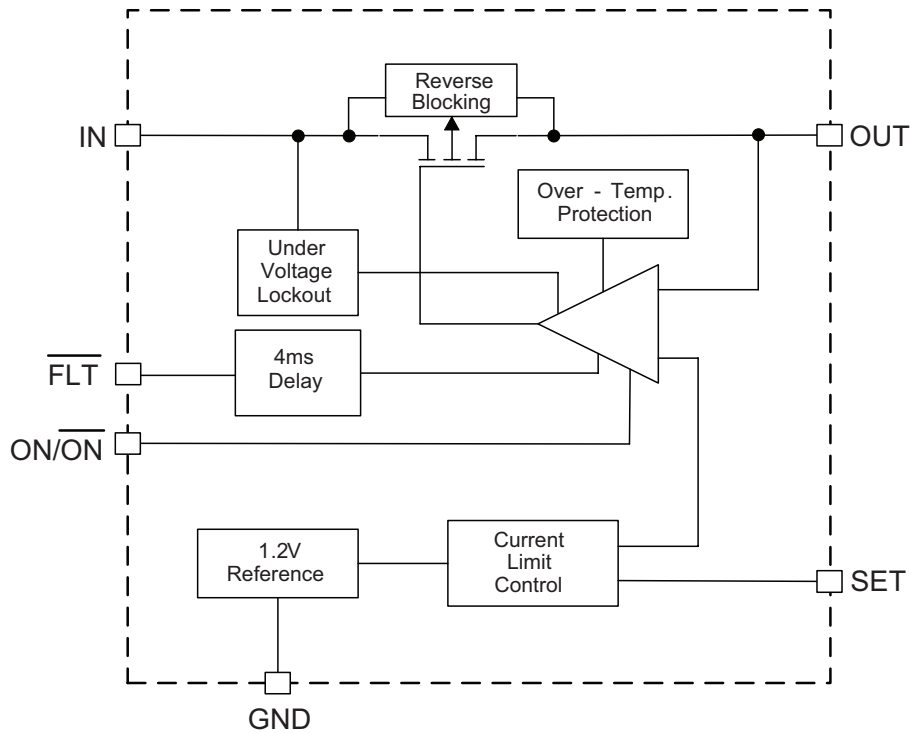
Output Short Response
 $V_{\text{IN}} = 5\text{V}$



Fault Blanking Time
 $V_{\text{IN}} = 5\text{V}$



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 exceeding a user programmed current limit level (I_{LM}), 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. 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 2.4V to 5.5V which, along with its extremely low operat-

ing current, makes it ideal for battery-powered applications. In cases where the input voltage drops below 2.4V, the AAT4616A MOSFET is protected from entering the saturated region of operation by being automatically shutting down via an under-voltage lockout circuit.

Current limit or over temperature conditions are reported by the open drain FAULT output. A 4ms 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 to flow 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, current can flow in either direction.

Application Information

Setting Current Limit

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:

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

where I_{LIM} is in mA and R_{SET} in $\text{k}\Omega$.

Table 1 summarizes resistor values for current limit settings. Use 1% tolerance metal film resistors for programming the desired current limit setting. Figure 1 shows the output current vs. output voltage with R_{SET} equal to 34.8k Ω .

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

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

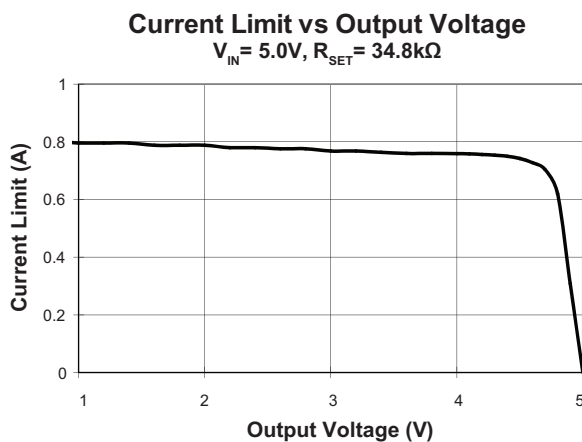


Figure 1: Current Limit vs Output Voltage with 34.8k Ω R_{SET} .

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, will flow for less than 1 μs 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 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 V_{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} . 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 0.47 μF) is required. No matter how large the output capacitor, 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 will allow 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 which run at lower voltages than the power planes themselves. The enable input ($\text{ON}/\overline{\text{ON}}$) of the AAT4616A 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 AAT4616A onto a capacitive load, the AAT4616A 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 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 4ms, 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 AAT4616A output from activating the FAULT Flag when they are initially attached. Pull-up resistances of 10kΩ to 100kΩ 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 5.5V, 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, 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:

$$T_{J(MAX)} = I_{MAX(OUT)-SW(MAX)}^2 \cdot R_{DS(ON)(MAX)} \cdot R_{\theta JA} + T_{A(MAX)}$$

where

- I_{MAX} is the maximum current required by the load,
- $R_{DS(ON)(MAX)}$ is the maximum rated $R_{DS(ON)}$ of the 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 the equation to solve for I_{MAX} , we get:

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

Note that $T_{J(MAX)}$ has been replaced by $T_{SD(MIN)}$, the minimum temperature required to activate the AAT4616A'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 85°C/W. Using the equation we get:

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

Evaluation Board Schematic

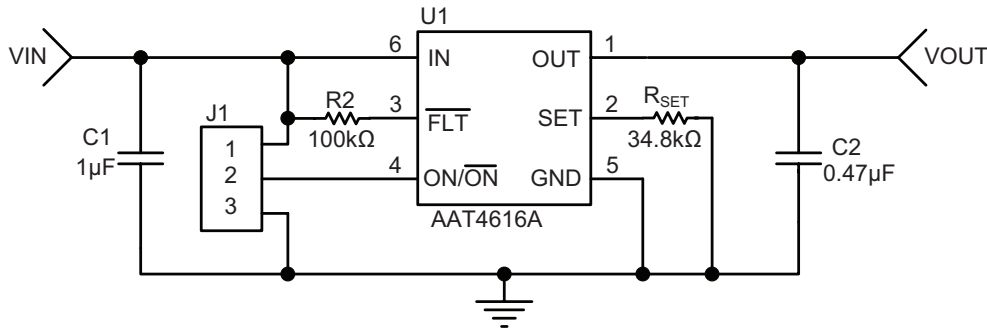
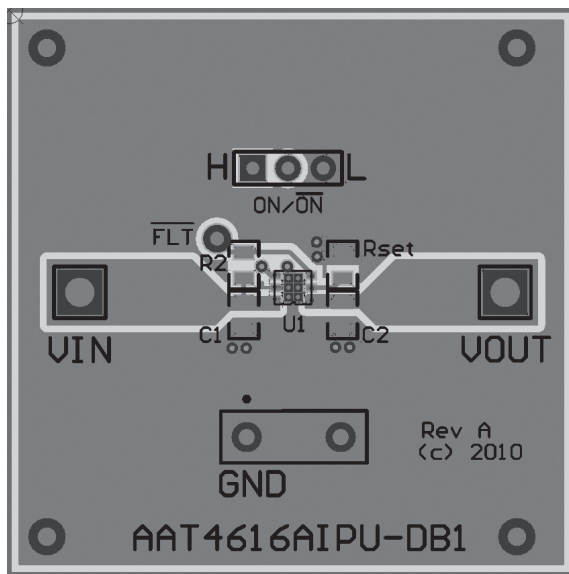
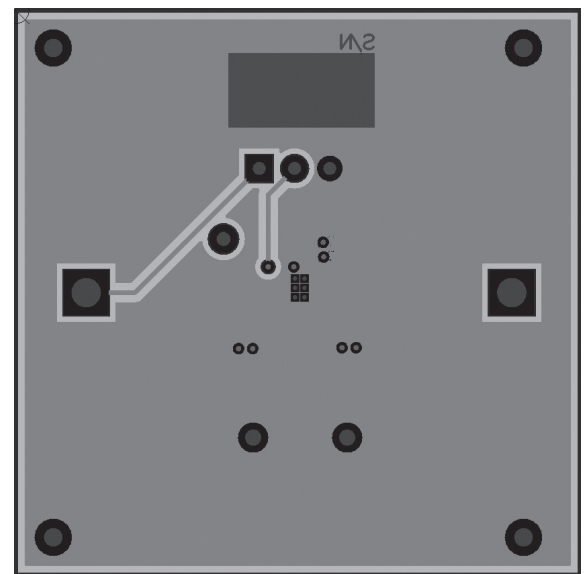


Figure 2: AAT4616A Evaluation Board Schematic

Evaluation Board Layout



(a): Top Side



(a): Bottom Side

Figure 3: AAT4616A Evaluation Board Layout

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

Table 2: AAT4616A Evaluation Board Bill of Materials.

Ordering Information

Enable Input	Package	Marking ¹	Part Number (Tape and Reel) ²
Active High	TDFN22-6	R9XYY	AAT4616AIPU-1-T1
Active Low	TDFN22-6	U4WBF	AAT4616AIPU-T1



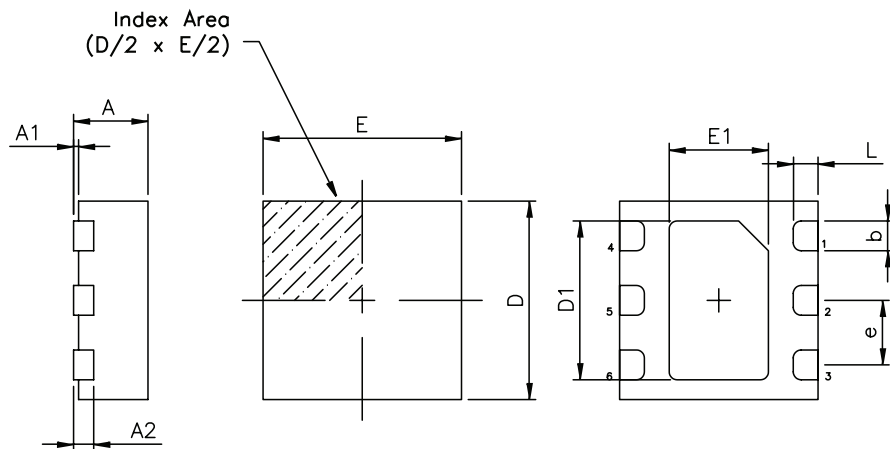
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Package Information

TDFN22-6

Dimension Table (Unit: mm or degree)

Symbol	Min	Typ	Max
A	0.70	0.75	0.80
A1	0.00	0.025	0.05
A2	0.203 REF		
D	1.95	2.00	2.05
E	1.95	2.00	2.05
D1	1.55	1.60	1.65
E1	0.95	1.00	1.05
b	0.25	0.30	0.35
e	0.65 BSC		
L	0.20	0.25	0.30



All dimensions in millimeters

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

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