

## 1.8A Current Limited P-Channel Switch

### General Description

The AAT4601 SmartSwitch is a member of Skyworks' Application Specific Power MOSFET™ (ASPM™) product family. It is a 1.8A current limited P-channel MOSFET power switch designed for high-side load switching applications. This switch operates with inputs ranging from 2.7V to 5.5V, making it ideal for both 3V and 5V systems. An integrated current-limiting circuit protects the input supply against large changes in load current which could cause the supply to fall out of regulation. The AAT4601 has protection from thermal overload which limits power dissipation and junction temperatures. The maximum current limit level will guarantee that 1.8A can be delivered to the load; the actual threshold is programmed with a resistor from the SET pin to ground. The quiescent supply current is typically 12μA. In shutdown mode, the supply current decreases to less than 1μA.

The AAT4601 is available in a Pb-free, 8-pin SOP package and is specified over the -40°C to +85°C temperature range.

### Features

- Input Voltage: 2.7V to 5.5V
- Programmable Over-Current Threshold
- Low Quiescent Current
  - 12μA Typical
  - Less Than 1μA with Switch Off
- Only 2.5V Needed for  $\overline{\text{ON}}$  Control
- Thermal Shutdown
- Fault Flag
- 2ms Fault Blanking
- Under-Voltage Lockout
- Temperature Range: -40°C to +85°C
- 4kV ESD Rating
- UL Approved—File No. E217765
- 8-Pin SOP Package

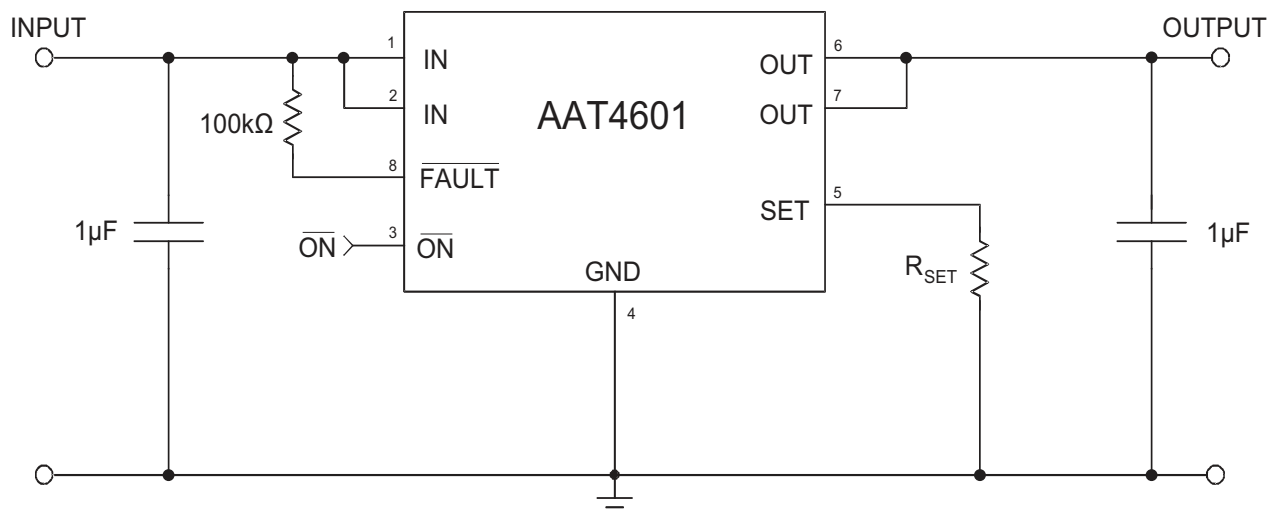
### Applications

- Hot Swap Supplies
- Notebook Computers
- Peripheral Ports
- USB Ports



UL Recognized Component

### Typical Application



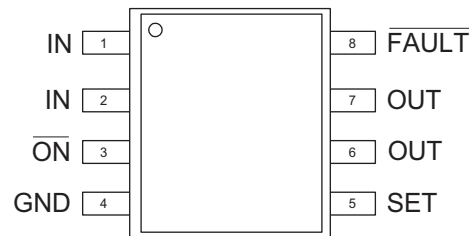
## 1.8A Current Limited P-Channel Switch

### Pin Descriptions

| Pin # | Symbol                    | Function  |
|-------|---------------------------|---|
| 1, 2  | IN                        | These pins are the input to the P-channel MOSFET source. Connect a 1 $\mu$ F capacitor from IN to GND.  |
| 3     | $\overline{\text{ON}}$    | Active low enable input. A logic low turns the switch on.   |
| 4     | GND                       | Ground.   |
| 5     | SET                       | Current limit set input. A resistor from SET to ground sets the current limit for the switch.   |
| 6, 7  | OUT                       | These pins are the P-channel MOSFET drain connection. Connect a 1 $\mu$ F capacitor from OUT to GND.  |
| 8     | $\overline{\text{FAULT}}$ | Fault indication output. This open-drain output goes low when in current limit or when the die temperature exceeds +135°C, with a 2ms delay after the fault event occurs. |

### Pin Configuration

**SOP-8**  
(Top View)



***1.8A Current Limited P-Channel Switch***

## Absolute Maximum Ratings<sup>1</sup>

$T_A = 25^\circ\text{C}$ , unless otherwise noted.

| Symbol              | Description                              | Value                  | Units            |
|---------------------|--|------------------------|------------------|
| $V_{IN}$            | IN to GND                                | -0.3 to 6              | V                |
| $V_{ON}, V_{FAULT}$ | $\overline{ON}$ , FAULT 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 Continuous Switch Current        | 3                      | A                |
| $T_J$               | Operating Junction Temperature Range     | -40 to 150             | $^\circ\text{C}$ |
| $T_{LEAD}$          | Maximum Soldering Temperature (at Leads) | 300                    |                  |
| $V_{ESD}$           | ESD Rating—HBM <sup>2</sup>              | 4                      | kV               |

## Thermal Characteristics<sup>3</sup>

| Symbol        | Description                | Value | Units                     |
|---------------|----------------------------|-------|---------------------------|
| $\Theta_{JA}$ | Maximum Thermal Resistance | 100   | $^\circ\text{C}/\text{W}$ |
| $P_D$         | Maximum Power Dissipation  | 1.25  | W                         |

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. Human body model is a 100pF capacitor discharged through a 1.5k $\Omega$  resistor into each pin.
3. Mounted on an FR4 printed circuit board.

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### Electrical Characteristics

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

| Symbol         | Description                                  | Conditions   | Min | Typ   | Max | Units       |
|----------------|--|--|-----|-------|-----|-------------|
| $V_{IN}$       | Operation Voltage                            |  | 2.7 |       | 5.5 | V           |
| $I_Q$          | Quiescent Current                            | $V_{IN} = 5V$ , $\overline{ON} = GND$ , $I_{OUT} = 0$  |     | 12    | 30  | $\mu A$     |
| $I_{Q(OFF)}$   | Off-Supply Current                           | $\overline{ON} = IN$ , $V_{IN} = 5.5V$                 |     | 0.004 | 1   |             |
| $I_{SD(OFF)}$  | Off-Switch Current                           | $\overline{ON} = IN$ , $V_{IN} = 5.5V$ , $V_{OUT} = 0$ |     | 0.07  | 15  |             |
| $V_{UVLO}$     | Under-Voltage Lockout                        | Rising Edge, 1% Hysteresis                             | 2.0 | 2.3   | 2.7 | V           |
| $R_{DS(ON)}$   | On Resistance                                | $V_{IN} = 5.0V$  |     | 70    | 120 | $m\Omega$   |
|                |  | $V_{IN} = 4.5V$  |     | 75    | 130 |             |
|                |  | $V_{IN} = 3.0V$  |     | 80    | 150 |             |
|                |  | $V_{IN} = 3.0V$ , $T_A = 25^{\circ}C$                  |     | 80    | 110 |             |
| $I_{LIM}$      | Current Limit                                | $R_{SET} = 2k\Omega$                                   | 510 | 715   | 920 | mA          |
| $I_{LIM(MIN)}$ | Minimum Current Limit                        |  |     | 375   |     |             |
| OTMP           | Shutdown Temperature                         | $V_{IN} = 5V$  |     | 125   |     | $^{\circ}C$ |
| $V_{ONL}$      | $\overline{ON}$ Input Low Voltage            |  |     |       | 0.8 | V           |
| $V_{ONH}$      | $\overline{ON}$ Input High Voltage           | $V_{IN} = 2.7V$ to $3.6V$                              | 2.0 |       |     |             |
|                |  | $V_{IN} = 4.5V$ to $5.5V$                              | 2.4 |       |     |             |
| $I_{ONSINK}$   | $\overline{ON}$ Input leakage                | $V_{ON} = 5.5V$  |     | 0.01  | 1   | $\mu A$     |
| $V_{FAULTL}$   | $\overline{FAULT}$ Logic Output Low Voltage  | $I_{SINK} = 1mA$                                       |     | 0.08  | 0.4 | V           |
| $I_{FSINK}$    | $\overline{FAULT}$ Logic Output High Leakage | $V_{FAULT} = 5.5V$                                     |     | 0.05  | 1   | $\mu A$     |
| $T_{RESP}$     | Current Limit Response Time                  | $V_{IN} = 5V$  |     | 2     |     | $\mu s$     |
| $T_{BLANK}$    | Fault Blanking Time After Turn-On            |  |     | 2     |     | ms          |
| $T_{OFF}$      | Turn-Off Time <sup>1</sup>                   | $V_{IN} = 5V$  |     |       | 20  | $\mu s$     |
| $T_{ON}$       | Turn-On Time <sup>1</sup>                    | $V_{IN} = 5V$  |     |       | 200 |             |

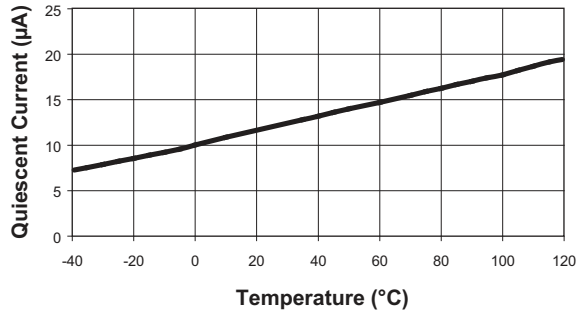
1. Guaranteed by design.

## 1.8A Current Limited P-Channel Switch

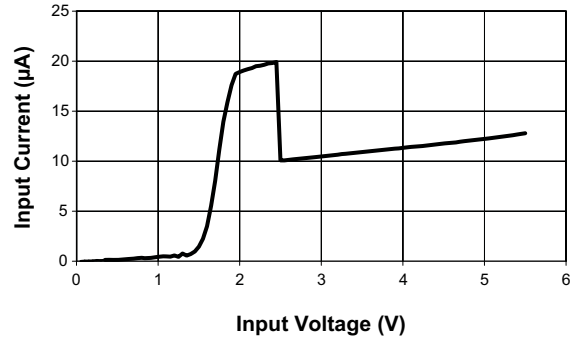
### Typical Characteristics

Unless otherwise noted,  $V_{IN} = 5V$ ,  $T_A = 25^\circ C$ .

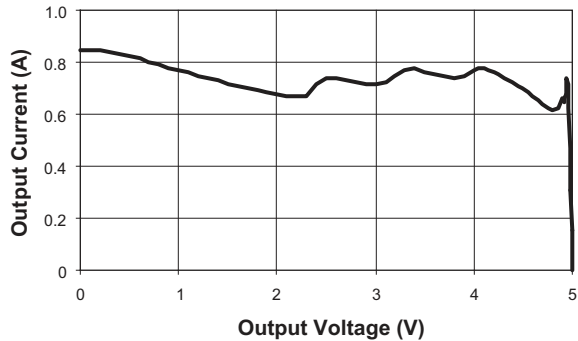
Quiescent Current vs. Temperature



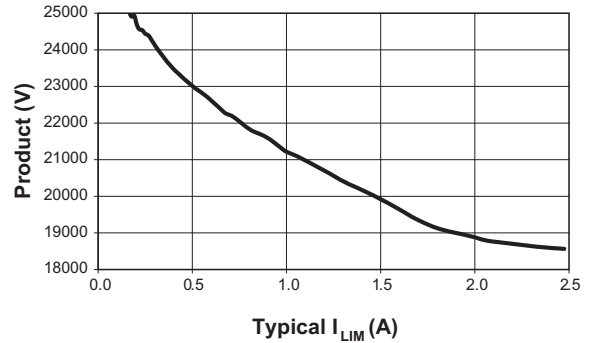
Quiescent Current



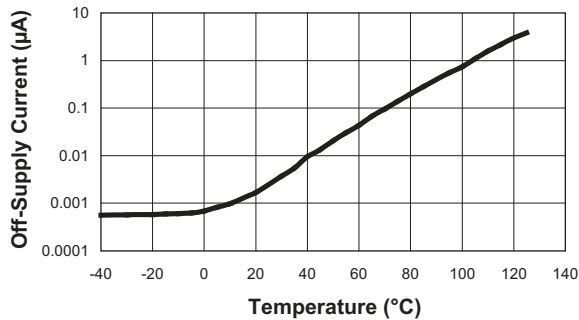
Current Limit  
( $R_{SET} = 2k\Omega$ ;  $V_{IN} = 5V$ )



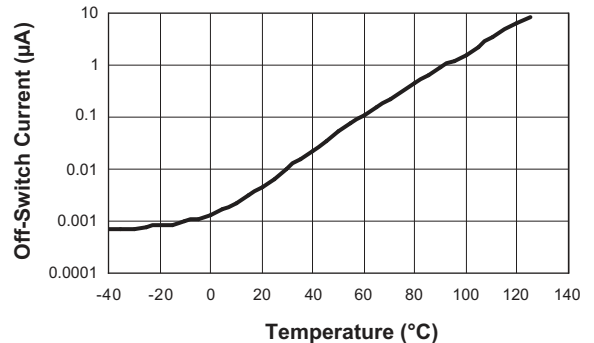
$R_{SET} * I_{LIM}$  Product vs.  $I_{LIM}$



Off-Supply Current vs. Temperature



Off-Switch Current vs. Temperature

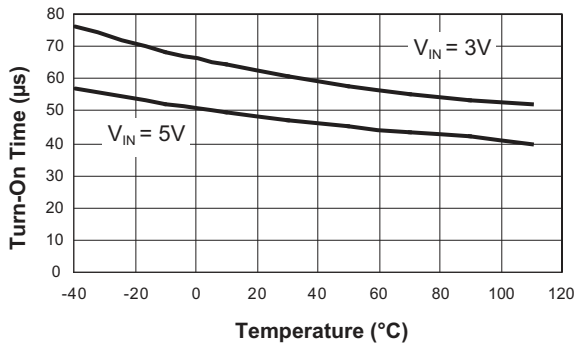


## 1.8A Current Limited P-Channel Switch

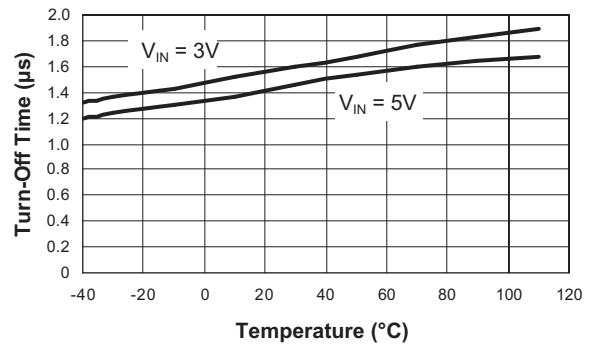
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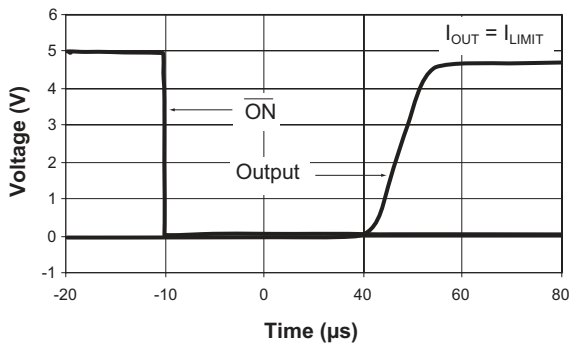
Turn-On Time vs. Temperature



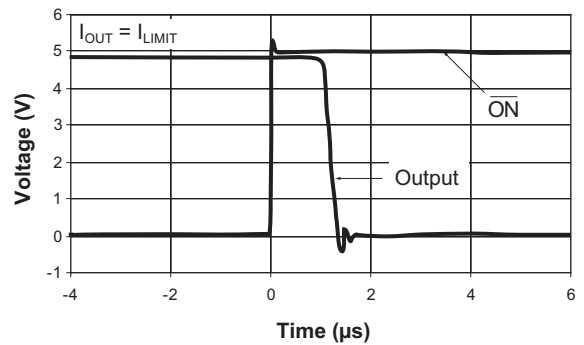
Turn-Off Time vs. Temperature



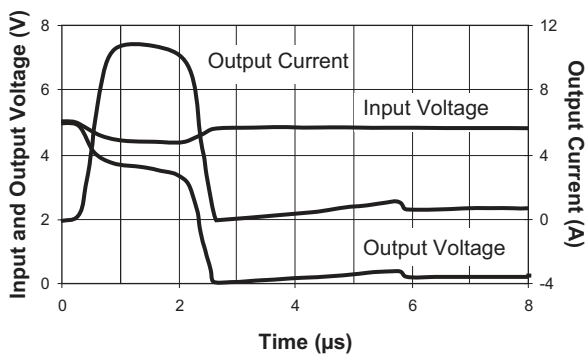
Switch Turn-On Time



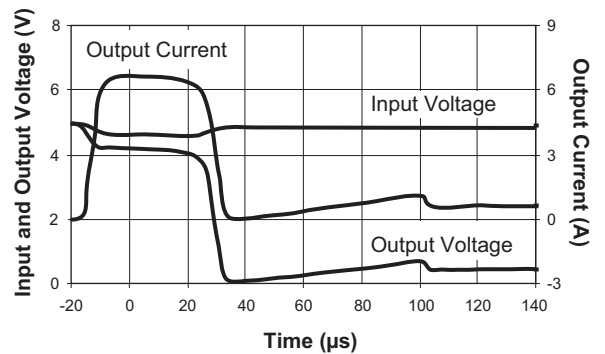
Switch Turn-Off Time



Short-Circuit Through 0.3Ω



Short-Circuit Through 0.6Ω

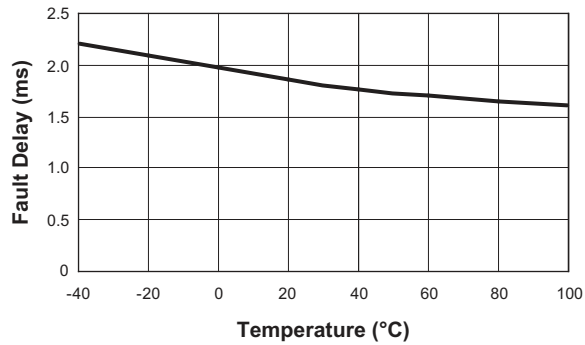


**1.8A Current Limited P-Channel Switch**

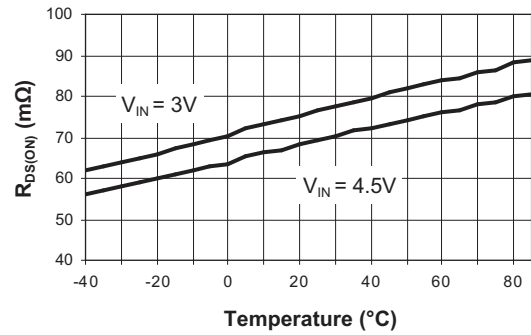
## Typical Characteristics

Unless otherwise noted,  $V_{IN} = 5V$ ,  $T_A = 25^\circ C$ .

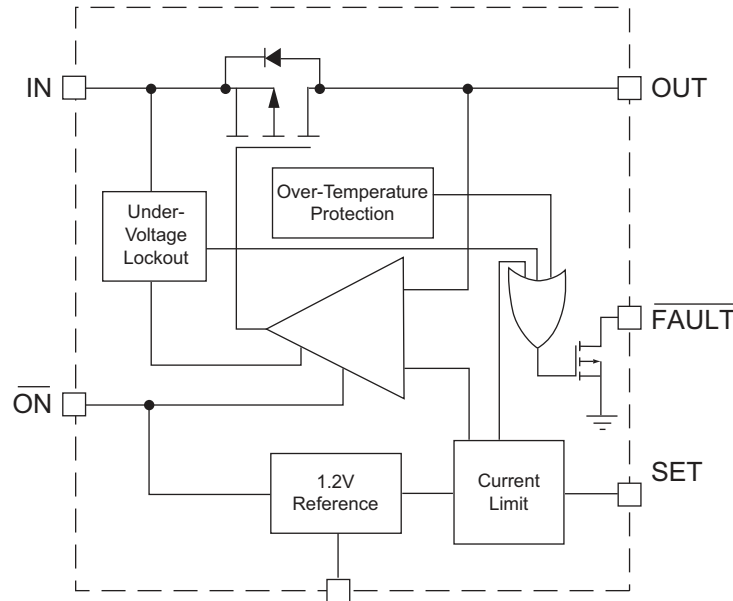
**Fault Delay vs. Temperature**



**$R_{DS(ON)}$  vs. Temperature**



### Functional Block Diagram



### Functional Description

The AAT4601 is an integrated MOSFET load switch with an adjustable current limit, over-temperature protection, level-shifted input, and a fault flag. The current limit control is combined with an over-temperature thermal limit circuit to provide a comprehensive system to protect the load switch under short-circuit or other adverse operating conditions. The AAT4601 is ideally suited for control and protection of peripheral ports such as USB, RS232, and parallel ports.

The current limit and over-temperature circuits will act independently. The device current limit is activated when the output load current exceeds an internal threshold level. The internal current limit threshold is determined by an external resistor connected between the SET pin and ground. The minimum current limit threshold is specified by  $I_{LIM(MIN)}$ . If the load switch ambient temperature becomes excessive or if a short-circuit condition persists, the die temperature will rise, causing the over-temperature protection circuit to activate.

If a current limit level less than  $I_{LIM(MIN)}$  is required, the AAT4601 can be used to operate in foldback current limit mode. To achieve this, an  $R_{SET}$  value can be chosen to program a current limit lower than  $I_{LIM(MIN)}$ ; in this case, when the load current reaches  $I_{LIM(MIN)}$ , the current will immediately drop, limiting at the programmed value.

If the current limit or over-temperature protection circuits are active for more than 2ms, the system will be informed via the  $\overline{FAULT}$  flag. The 2ms delay allows the AAT4601 to be turned on into capacitive loads without activating the  $\overline{FAULT}$  flag. The open drain  $\overline{FAULT}$  output can be connected directly to system controllers driven by voltage levels less than the IN pin voltage without additional level shifting circuitry.

The load switch is turned off by applying a logic high level to the  $\overline{ON}$  pin. The AAT4601 typically consumes 12 $\mu$ A when operating; when off, the device draws less than 1 $\mu$ A. In the off state, current is prevented from flowing between the input and output. The  $\overline{ON}$  function has logic level thresholds that allow the AAT4601 to be TTL compatible and may also be controlled by 2.5V to 5.0V CMOS circuits. The voltage level on either  $\overline{ON}$  or  $\overline{FAULT}$  should not exceed the input supply level present on the IN pin.



## 1.8A Current Limited P-Channel Switch

### Applications Information

#### Setting Current Limit

A simple three-step procedure can be used to adjust the AAT4601's current limit. First, the maximum current required by the load should be determined. Second, select a resistor that guarantees adequate current is available to the load under normal conditions. Finally, the maximum current that can pass through the switch can be calculated and compared to the maximum current available.

**Step 1:** The maximum current required by a load is usually defined in port specifications design application references. For example, USB ports may be specified to support loads of up to 500mA.

**Step 2:** The most convenient method for determining a current limit resistor value is to look it up in Table 1, "Current Limit  $R_{SET}$  Values.". Find the lowest current value that is greater than the maximum load current in the given application; refer to the column, "Device Will Not Current Limit Below." The resistor value needed is in the corresponding row named " $R_{SET}$ ." For example, a USB port requires 500mA. The lowest level where the device will current limit above 500mA is 516mA. The corresponding resistor value for  $R_{SET}$  would be 2k $\Omega$ .

**Step 3:** Now the required resistor value has been determined. The maximum current that can be drawn, even with a short circuit applied to the output, can be determined by referring to the column labeled, "Device Always Current Limits Below." If the power supply connected to the AAT4601's input can provide this current level, the power supply voltage will not collapse when a short circuit is applied to the load switch output. For example, a notebook computer has a USB port which is powered by an AAT4601 with a 2k $\Omega$  resistor connected between the SET pin and GND. If the power supply connected to the AAT4601's IN pin can provide more than 917mA, this supply will remain in regulation even if a short circuit is applied to the USB port.

| $R_{SET}$<br>( $\Omega$ ) | Current<br>Limit Typ<br>(mA) | Device Will<br>Not Current<br>Limit Below<br>(mA) | Device Always<br>Current Limits<br>Below (mA) |
|---------------------------|------------------------------|---|---|
| 0                         | 2510                         | 1807  | 3213  |
| 10                        | 2463                         | 1773  | 3152  |
| 20                        | 2423                         | 1745  | 3102  |
| 30                        | 2386                         | 1718  | 3054  |
| 36                        | 2361                         | 1700  | 3022  |
| 47                        | 2332                         | 1679  | 2985  |
| 56                        | 2297                         | 1654  | 2940  |
| 68                        | 2258                         | 1626  | 2890  |
| 82                        | 2214                         | 1594  | 2834  |
| 100                       | 2161                         | 1556  | 2766  |
| 120                       | 2107                         | 1517  | 2697  |
| 150                       | 2028                         | 1460  | 2596  |
| 200                       | 1918                         | 1381  | 2455  |
| 240                       | 1840                         | 1325  | 2355  |
| 300                       | 1737                         | 1251  | 2223  |
| 360                       | 1649                         | 1187  | 2111  |
| 470                       | 1585                         | 1141  | 2029  |
| 510                       | 1529                         | 1101  | 1957  |
| 560                       | 1466                         | 1055  | 1876  |
| 620                       | 1397                         | 1006  | 1788  |
| 680                       | 1334                         | 960   | 1707  |
| 750                       | 1266                         | 911   | 1620  |
| 820                       | 1206                         | 869   | 1544  |
| 910                       | 1144                         | 823   | 1464  |
| 1000                      | 1089                         | 784   | 1394  |
| 1100                      | 1034                         | 745   | 1324  |
| 1200                      | 986                          | 710   | 1262  |
| 1300                      | 941                          | 677   | 1204  |
| 1500                      | 865                          | 623   | 1107  |
| 1600                      | 829                          | 597   | 1061  |
| 1800                      | 769                          | 554   | 985   |
| 2000                      | 716                          | 516   | 917   |
| 2200                      | 673                          | 485   | 861   |
| 2400                      | 633                          | 456   | 811   |
| 2700                      | 582                          | 419   | 745   |
| 3000                      | 539                          | 388   | 690   |
| 3300                      | 502                          | 362   | 643   |
| 3600                      | 470                          | 339   | 602   |
| 3900                      | 442                          | 318   | 565   |
| 4300                      | 410                          | 295   | 524   |
| 4700                      | 382                          | 275   | 489   |
| 5100                      | 358                          | 258   | 458   |
| 5600                      | 332                          | 239   | 424   |
| 6200                      | 306                          | 220   | 392   |
| 6800                      | 283                          | 204   | 362   |
| 7500                      | 268                          | 193   | 343   |

**Table 1: Current Limit  $R_{SET}$  Values.**

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### Operation in Current Limit

If an excessive load is applied to the output of an AAT4601, the load current will be limited by the device's current limit circuitry. Refer to Figure 1, Overload Operation. If a short circuit were to occur on the load, it would demand more current than allowed by the internal current limiting circuit and the voltage at the AAT4601's output would drop. This causes the AAT4601 to dissipate more power than in normal operation, causing the die temperature to increase. When die temperature exceeds the internal over-temperature threshold, the AAT4601 will shut down. After shutting down, the AAT4601 cools to a level below the over-temperature threshold, at which point it will start up again. The AAT4601 will continue to cycle off and on until one of the following events occurs: the load current is reduced to a level below the AAT4601's current limit setting; the input power is removed; or the output is turned off by a logic high level applied to the  $\overline{\text{ON}}$  pin.

### Thermal Considerations

Since the AAT4601 has internal current limit and over-temperature protection, junction temperature is rarely a concern. If an application requires a large load current in a high-temperature operating environment, there is the possibility that the over-temperature protection circuit, rather than the current limit circuit, will regulate the current available to the load. In these applications, the maximum current available without risk of activation of the over-temperature circuit can be calculated. The maximum internal temperature while current limit is not active can be calculated using Equation 1:

$$\text{Eq. 1: } T_{J(\text{MAX})} = I_{\text{MAX}}^2 \cdot R_{\text{DS(ON)(MAX)}} \cdot R_{\theta\text{JA}} + T_{\text{A(MAX)}}$$

In Equation 1,  $I_{\text{MAX}}$  is the maximum current required by the load.  $R_{\text{DS(ON)(MAX)}}$  is the maximum rated  $R_{\text{DS(ON)}}$  of the AAT4601 at high temperature.  $R_{\theta\text{JA}}$  is the thermal resistance between the AAT4601's die and the board onto which it is mounted.  $T_{\text{A(MAX)}}$  is the maximum ambient temperature for the printed circuit board assembly under the AAT4601 when the load switch is not dissipating power. Equation 1 can be transformed to provide  $I_{\text{MAX}}$ ; Refer to Equation 2:

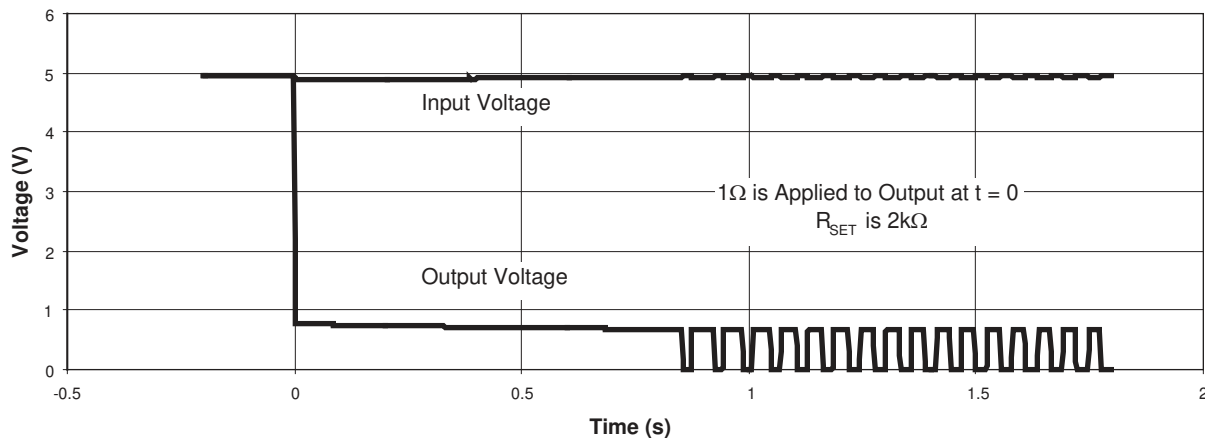
$$\text{Eq. 2: } I_{\text{MAX}} = \sqrt{\frac{T_{\text{SD(MIN)}} - T_{\text{A(MAX)}}}{R_{\text{DS(ON)(MAX)}} \cdot R_{\theta\text{JA}}}}$$

$T_{\text{SD(MIN)}}$  is the minimum temperature required to activate the AAT4601's over-temperature protection. With a typical specification of 125°C, 115°C is a safe minimum value to use.

For example, a portable device is specified to operate in a 50°C environment. The printed circuit board assembly will operate at temperatures as high as 85°C. This portable device has a sealed case and the area of the printed board assembly is relatively small, causing  $R_{\theta\text{JA}}$  to be approximately 120°C/W. Using Equation 2:

$$\text{Eq. 3: } I_{\text{MAX}} = \sqrt{\frac{115^\circ\text{C} - 85^\circ\text{C}}{0.13\Omega \cdot 120^\circ\text{C/W}}} = 1.4\text{A}$$

If this system requires less than 1.4A, the thermal limit will not activate during normal operation.



**Figure 1: Overload Operation.**

## ***1.8A Current Limited P-Channel Switch***

### **Input Capacitor**

The input capacitor serves two purposes. First, it protects the source power supply from transient current effects generated by the application load circuit. If a short circuit is suddenly applied to the output of an AAT4601, there is a microsecond-long period during which a large current can flow before the current limit circuitry activates; refer to the characteristic curve, "Short-Circuit Through  $0.3\Omega$ ." A properly sized input capacitor can dramatically reduce the load switch input transient response effects seen by the power supply and other circuitry upstream from the AAT4601.

The second purpose of the input capacitor is to prevent transient events generated by the load circuit from affecting operation of the AAT4601. For example, if an AAT4601 is used in a circuit that operates from a 3V power supply with poor step load response, it is possible that turning on the load switch could cause the input power supply to droop below the AAT4601's under-voltage lockout threshold. This drop in voltage would cause the AAT4601 to turn off until the input power supply voltage recovers. Since this cycle would be self-perpetuating, the entire circuit could be seen to be unstable. In the very rare case where capacitor cost is prohibitive, the output load circuit should be slew rate limited when turned on.

### **Output Capacitor**

In order to insure stability while the device current limit is active, a small capacitance of approximately  $1\mu\text{F}$  should be used. When the AAT4601 is activated using the  $\overline{\text{ON}}$  function, there are no momentary current transients, as in the case when a short circuit is suddenly applied to a device that is already on; refer to the characteristic curve, "Switch Turn-On Time." No matter how big the output capacitor, output current is limited to the value allowed by the threshold determined by  $R_{\text{SET}}$  and the internal current limiting circuitry. This permits very large output capacitors to be used.

For example, USB ports are specified to have at least  $120\mu\text{F}$  of downstream capacitance from their controlling power switch. An output capacitance as large as  $1000\mu\text{F}$  would not disturb the input power supply to the AAT4601 used to control the USB port.

### **ON Input**

When the AAT4601 is in the off state, the output is an open circuit and the device quiescent current consumption is reduced to less than  $1\mu\text{A}$ . The  $\overline{\text{ON}}$  threshold volt-

age is set to allow the AAT4601 to be controlled by 5V TTL levels, as well as CMOS power from 2.5V to 5V. The ON function control voltage level should not exceed the input supply level applied to the IN pin.

### **FAULT Output**

A  $\overline{\text{FAULT}}$  flag is provided to alert a system if the load switch is not receiving a sufficient voltage level to properly operate. If either the current limit or over-temperature circuits in any combination are active for more than approximately 2ms continuously, the  $\overline{\text{FAULT}}$  pin is pulled to ground internally through a  $100\Omega$  resistance. The 2ms delay on the  $\overline{\text{FAULT}}$  function is intended to prevent capacitive loads connected to the load switch output from activating  $\overline{\text{FAULT}}$  when the device is turned on. The placement of a pull-up resistor between the  $\overline{\text{FAULT}}$  pin and the IN pin is recommended. Reasonable values for the pull-up resistor should range from  $10\text{k}\Omega$  to  $100\text{k}\Omega$ . Since  $\overline{\text{FAULT}}$  is an open drain terminal, it may be pulled up to any voltage that is not greater than the level present on the IN pin. This is done to allow the AAT4601 to signal ancillary circuitry that is powered by a voltage level less than the level on the IN pin.

### **Reverse Voltage**

The AAT4601 is designed to control current flowing from IN to OUT. If a voltage is applied to OUT which is greater than that on IN, a large resulting reverse current may flow, potentially damaging the AAT4601.

### **Printed Circuit Board Layout Recommendations**

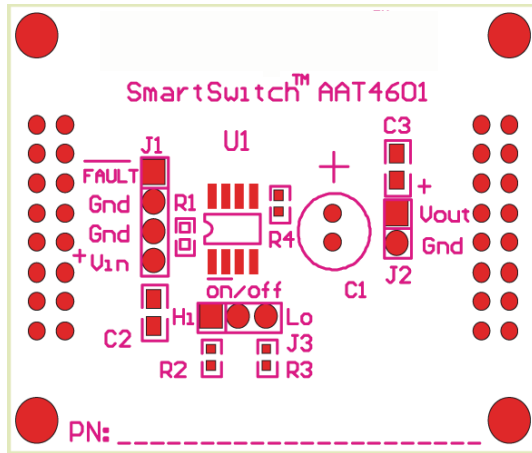
For proper thermal management, and to take advantage of the low  $R_{\text{DS(ON)}}$  of the AAT4601, a few circuit board layout rules should be followed:  $V_{\text{IN}}$  and  $V_{\text{OUT}}$  should be routed using wider than normal traces, and GND should be connected to a ground plane. For best performance,  $C_{\text{IN}}$  and  $C_{\text{OUT}}$  should be placed close to the package pins.

### **Evaluation Board Layout**

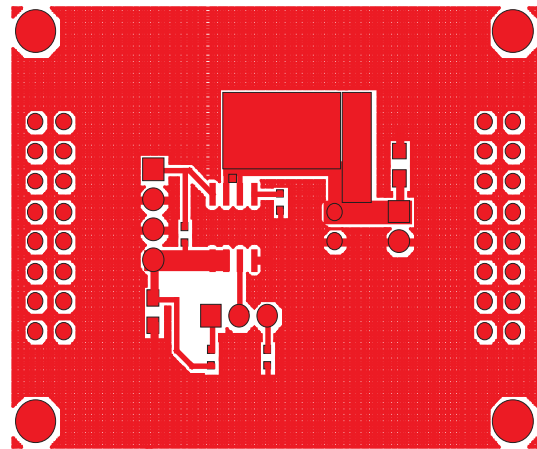
The AAT4601 evaluation layout follows the printed circuit board layout recommendations, and can be used for good applications layout.

Note: Board layout shown is not to scale.

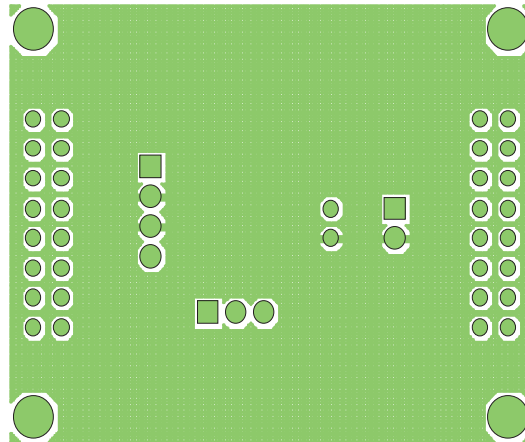
## 1.8A Current Limited P-Channel Switch



**Figure 1: AAT4601 Evaluation Board Top Side Silk Screen Assembly Drawing.**



**Figure 2: AAT4601 Evaluation Board Component Side Layout.**



**Figure 3: AAT4601 Evaluation Board Solder Side Layout.**

## 1.8A Current Limited P-Channel Switch

### Ordering Information

| Package | Marking <sup>1</sup> | Part Number (Tape and Reel) <sup>2</sup> |
|---------|----------------------|--|
| SOP-8   | 4601                 | AAT4601IAS-T1                            |



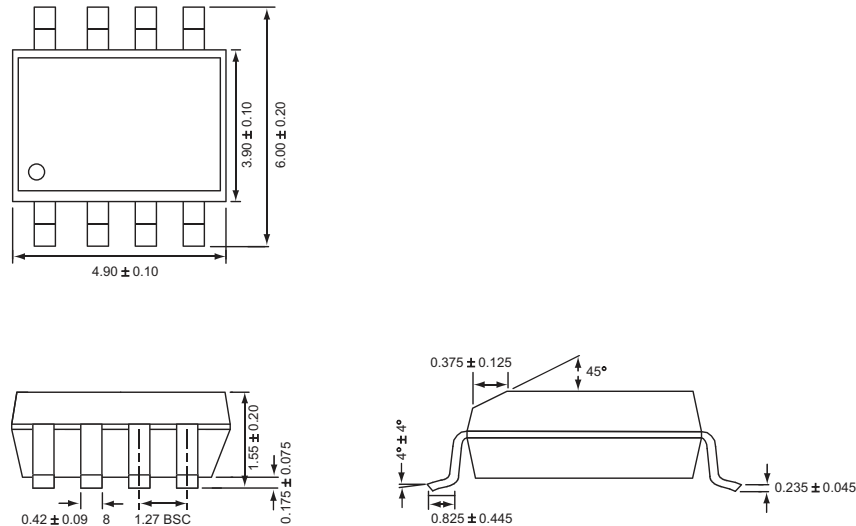
Skyworks Green™ products are compliant with all applicable legislation and are halogen-free.



For additional information, refer to *Skyworks Definition of Green™*, document number SQ04-0074.

### Package Information

#### SOP-8



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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