

General Description

The AAT4290 and AAT4291 SmartSwitch™ products are members of Skyworks' Application Specific Power MOSFET (ASPM™) product family. The AAT4290 and AAT4291 are five and three P-channel MOSFETs, respectively, configured for use as a microprocessor I/O expander. Having independent drain outputs and a common source input, they operate with an input voltage ranging from 1.8V to 5.5V, making them ideal for 2.5V, 3.3V, or 5V systems, as well as systems powered by lithium-ion/polymer batteries. Each switch features a 500ns turn-on time. The switch states are controlled by Skyworks' Simple Serial Control (S²Cwire™) interface which permits ease of control and efficiency of size. The quiescent supply current is very low, typically 4.5µA. In shutdown mode, the supply current is reduced to less than 1µA.

The AAT4290 and AAT4291 are offered in a Pb-free, 8-pin SC70JW package specified over the -40°C to +85°C temperature range.

A typical application circuit is shown in Figure 1. The pin configurations are shown in Figure 2. A functional block diagram of the AAT4290/4291 is provided in Figure 3.

Features

- 1.8V to 5.5V Input Voltage Range
- 5 or 3 Independent Load Switches
- S²Cwire Interface
- 1.1Ω R_{DS(ON)} Per Switch
- Low Quiescent Current
 - 4.5µA Typical
 - 0.1µA in Shutdown
- -40°C to +85°C Temperature Range
- 8-Pin SC70JW Package

Applications

- Cell Phones
- I/O Expansion
- Multiple Low Power Switching
- Personal Communication Devices
- Portable Electronic Devices

Typical Application

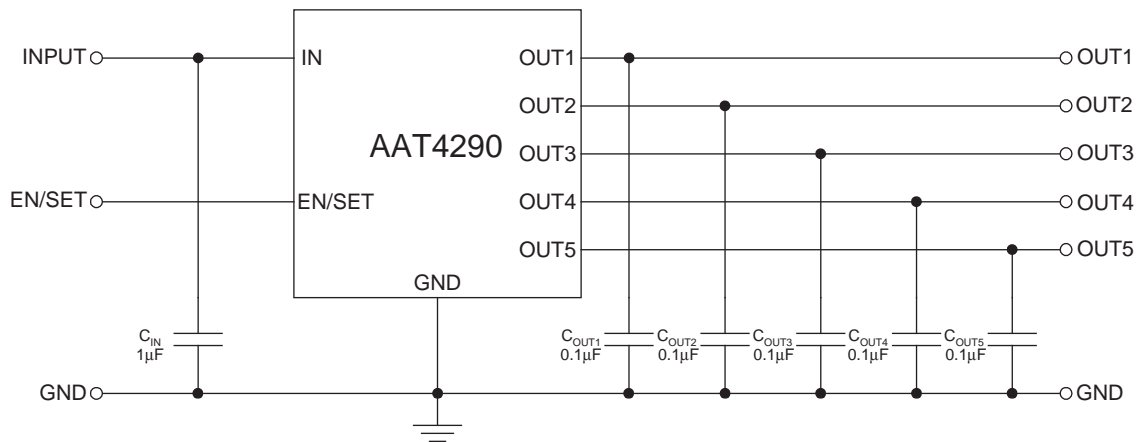


Figure 1. Typical Application Circuit.

AAT4290/4291**I/O Expander Load Switches with Serial Control****Pin Descriptions**

Pin #		Symbol	Function
AAT4290	AAT4291		
1	1	IN	Input power supply is connected to the P-channel MOSFET sources. Connect a 1 μ F capacitor from IN to GND.
2	7	OUT2	P-channel MOSFET drain.
3	6	OUT1	P-channel MOSFET drain.
4	4	EN/SET	Input control pin using S ² Cwire serial interface. The device records rising edges of the clock and decodes them into 32 states (8 states for AAT4291) which controls the ON/OFF states of the MOSFETs. See Table 1 and Table 2 for output settings.
5	5	GND	Ground connection.
6	N/A	OUT5	P-channel MOSFET drain.
7	N/A	OUT4	P-channel MOSFET drain.
8	8	OUT3	P-channel MOSFET drain.
N/A	2, 3	N/C	Not connected.

Pin Configuration

Figure 2. AAT4290/4291 Pinout – 8-pin SC70JW (Top View).

AAT4290/4291**I/O Expander Load Switches with Serial Control****Absolute Maximum Ratings¹**

Symbol	Description	Value	Units
V _{IN}	IN to GND	-0.3 to 6.0	V
V _{OUT}	OUT to GND	-0.3 to V _{IN} + 0.3	V
V _{EN/SET}	EN/SET to GND	-0.3 to 6.0	V
I _{MAX}	Maximum Continuous Switch Current	250	mA
T _{STORAGE}	Storage Temperature Range	-65 to 150	°C
V _{ESD}	ESD Rating - HBM ²	4000	V

Thermal Characteristics

Symbol	Description	Value	Units
θ _{JA}	Thermal Resistance ³	225	°C/W
P _D	Maximum Power Dissipation (T _A = 25°C) ⁴	440	mW

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. Only one Absolute Maximum Rating should be applied at any one time.
2. Human body model is a 100pF capacitor discharged through a 1.5kΩ resistor to each pin.
3. Mounted on the board.
4. Derate 4.4mW/°C above 25°C.

AAT4290/4291**I/O Expander Load Switches with Serial Control****Electrical Characteristics**

$V_{IN} = 5.0V$, $T_A = -40^{\circ}C$ 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		1.8		5.5	V
I_Q	Quiescent Current	$V_{IN} = 5.5V$, $EN/SET = V_{IN}$, $I_{OUT} = 0$, All Switches ON		4.5	8	μA
$I_{Q(OFF)}$	Off Supply Current	$EN/SET = 0$, $V_{IN} = 5.5V$, V_{OUTn} Open			1	μA
$I_{SD(OFF)}$	Off Switch Current	$EN/SET = 0$, $V_{IN} = 5.5V$, $V_{OUTn} = 0$		0.1	1	μA
V_{UVLO}	Under-Voltage Lockout	V_{IN} Falling		1.2		V
$V_{UVLO(hys)}$	Under-Voltage Lockout Hysteresis			250		mV
$R_{DS(ON)}$	On Resistance	$V_{IN} = 1.8V$, $T_A = 25^{\circ}C$		2.5	3.8	Ω
		$V_{IN} = 3.0V$, $T_A = 25^{\circ}C$		1.5	2.2	
		$V_{IN} = 4.2V$, $T_A = 25^{\circ}C$		1.2	1.8	
		$V_{IN} = 5.0V$, $T_A = 25^{\circ}C$		1.1	1.7	
T_{CRDS}	On Resistance Temperature Coefficient			2800		ppm $^{\circ}C$
AAT4290-1 and AAT4291-1						
$T_{D(ON)}$	Output Turn-On Delay Time	$V_{IN} = 5V$, $R_{LOAD} = 500\Omega$, $C_{OUT} = 0.1\mu F$		40		ns
T_R	Turn-On Rise Time	$V_{IN} = 5V$, $R_{LOAD} = 500\Omega$, $C_{OUT} = 0.1\mu F$		270		ns
$T_{D(OFF)}$	Turn-Off Delay Time	$V_{IN} = 5V$, $R_{LOAD} = 500\Omega$		40		ns
EN/SET						
$V_{EN(L)}$	Enable Threshold Low	$V_{IN} = 1.8V$			0.4	V
$V_{EN(H)}$	Enable Threshold High	$V_{IN} = 5.5V$	1.6			V
T_{LO}	EN/SET Low Time	$V_{EN/SET} < 0.4V$	100			ns
T_{HI}	Minimum EN/SET High Time	$V_{IN} \leq 2.5V$			500	ns
		$V_{IN} > 2.5V$			250	
T_O	EN/SET Off Timeout			2.6	4.0	μs
T_{LAT}	EN/SET Latch Timeout			2.6	4.0	μs
I_{SINK}	EN/SET Input Leakage	$V_{EN/SET} = 5.5V$		0.01	1	μA

1. The AAT4290/91 is guaranteed to meet performance specifications over the $-40^{\circ}C$ to $+85^{\circ}C$ operating temperature range and is assured by design, characterization, and correlation with statistical process controls.

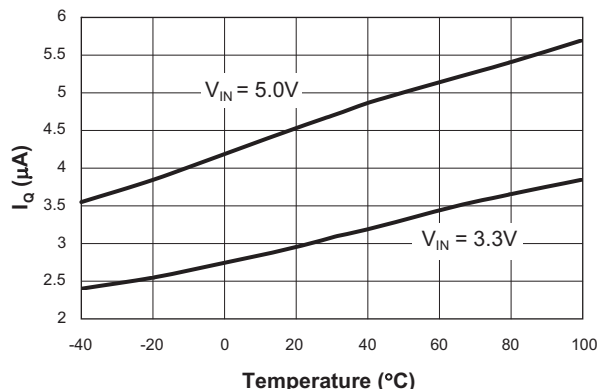
AAT4290/4291

I/O Expander Load Switches with Serial Control

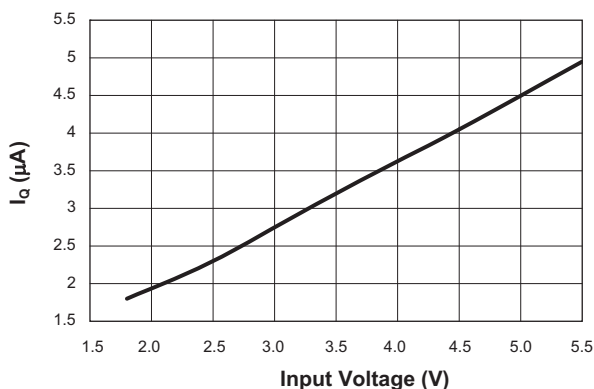
Typical Characteristics

Unless otherwise noted, $V_{IN} = 5V$, $C_{IN} = 1\mu F$, $C_{OUTX} = 0.1\mu F$, $T_A = 25^\circ C$.

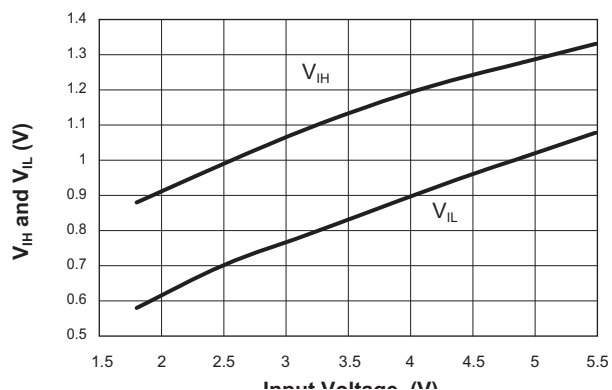
Quiescent Current vs. Temperature



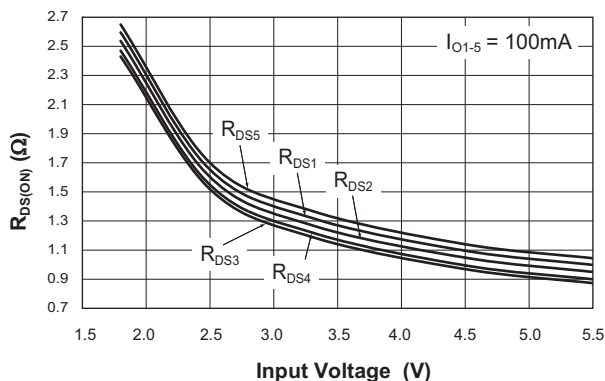
Quiescent Current vs. Input Voltage



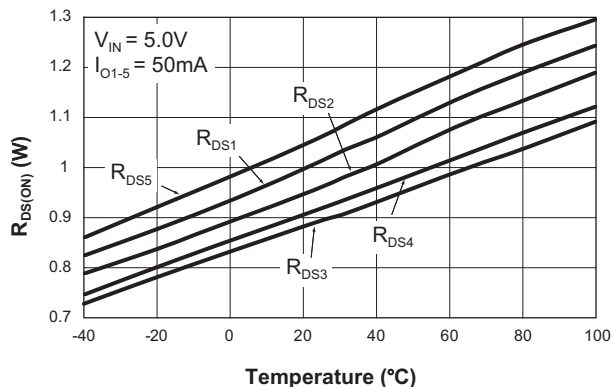
V_{IH} and V_{IL} vs. Input Voltage



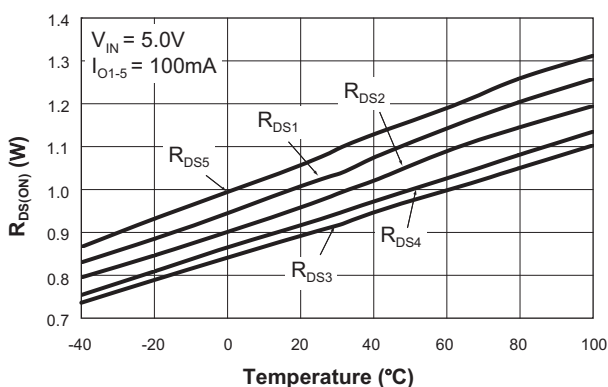
$R_{DS(ON)}$ vs. Input Voltage



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



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



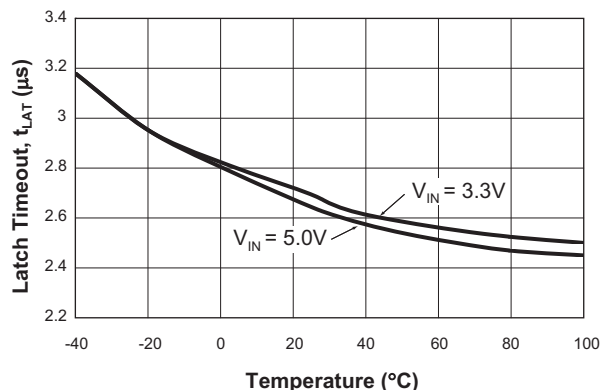
AAT4290/4291

I/O Expander Load Switches with Serial Control

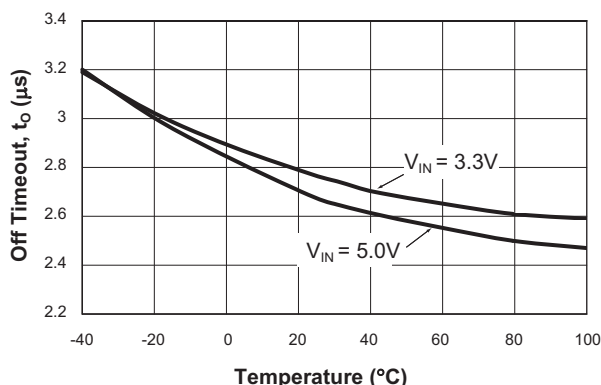
Typical Characteristics

Unless otherwise noted, $V_{IN} = 5V$, $C_{IN} = 1\mu F$, $C_{OUTX} = 0.1\mu F$, $T_A = 25^\circ C$.

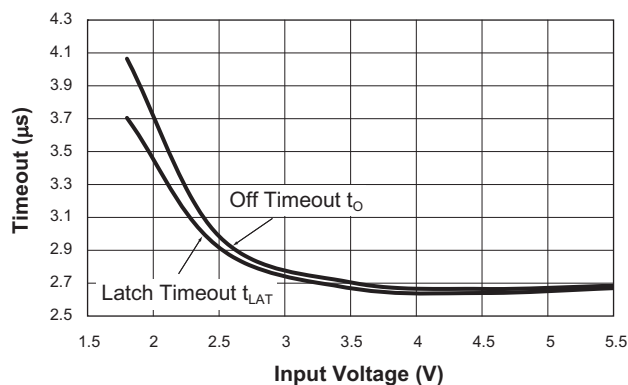
EN/SET Latch Timeout vs. Temperature



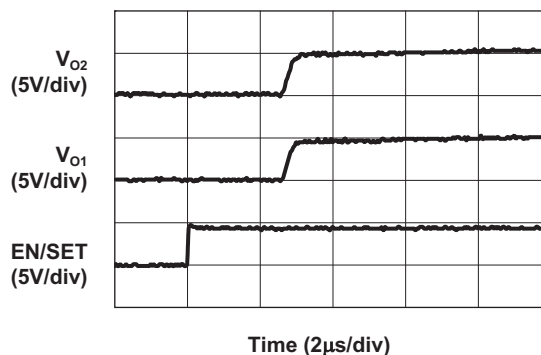
EN/SET Off Timeout vs. Temperature



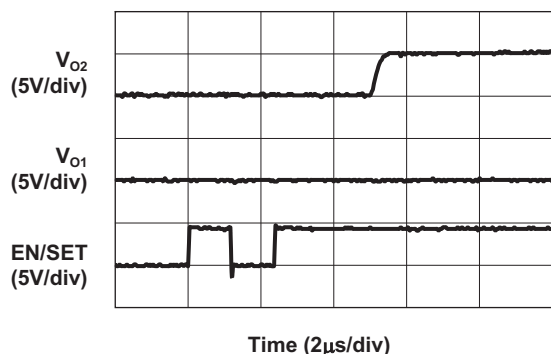
EN/SET Timeout vs. Input Voltage



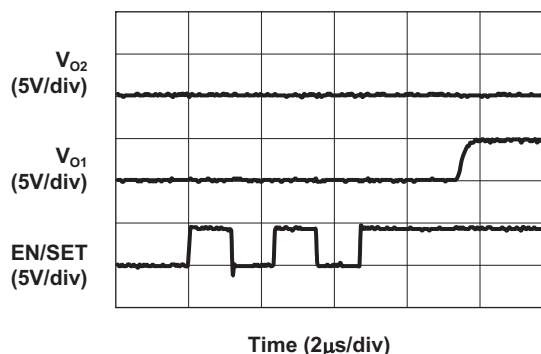
Turn-On Characteristic
($V_{IN} = 5V$, $R_{L1} = R_{L2} = 50\Omega$; $C_{O1} = C_{O2} = 0.1\mu F$)



Turn-On Characteristic
($V_{IN} = 5V$; $R_{L1} = R_{L2} = 50\Omega$; $C_{O1} = C_{O2} = 0.1\mu F$)



Turn-On Characteristic
($V_{IN} = 5V$; $R_{L1} = R_{L2} = 50\Omega$; $C_{O1} = C_{O2} = 0.1\mu F$)



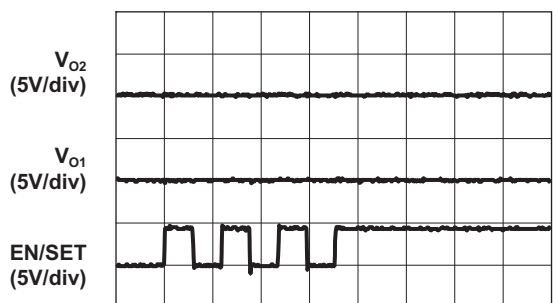
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I/O Expander Load Switches with Serial Control

Typical Characteristics

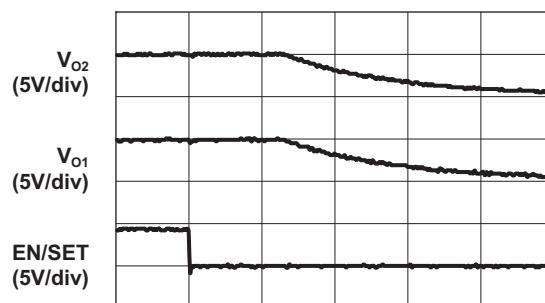
Unless otherwise noted, $V_{IN} = 5V$, $C_{IN} = 1\mu F$, $C_{OUTX} = 0.1\mu F$, $T_A = 25^\circ C$.

Turn-On Characteristic
($V_{IN} = 5V$; $R_{L1} = R_{L2} = 50\Omega$; $C_{O1} = C_{O2} = 0.1\mu F$)



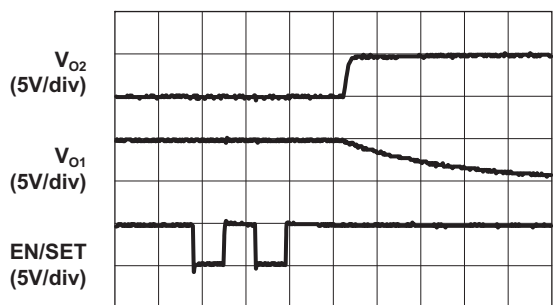
Time (2 μs /div)

Turn-Off Characteristic
($V_{IN} = 5V$; $R_{L1} = R_{L2} = 50\Omega$; $C_{O1} = C_{O2} = 0.1\mu F$)



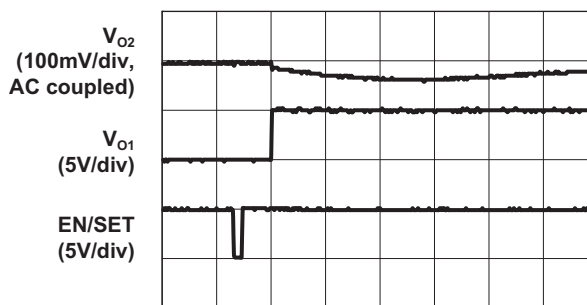
Time (2 μs /div)

Transition of Outputs
($V_{IN} = 5V$; $R_{L1} = R_{L2} = 50\Omega$; $C_{O1} = C_{O2} = 0.1\mu F$)



Time (2 μs /div)

Turn-On Transient Characteristic
($V_{IN} = 5V$; $R_{L1} = R_{L2} = 50\Omega$)



Time (5 μs /div)

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I/O Expander Load Switches with Serial Control

Functional Block Diagram

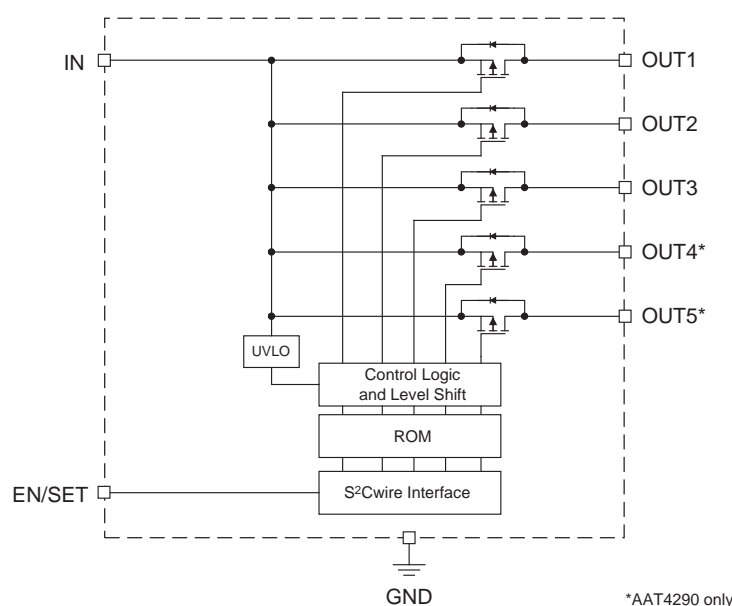


Figure 3. AAT4290/4291 Functional Block Diagram.

Functional Description

The AAT4290 consists of five P-channel MOSFET power switches designed for I/O expansion applications. The AAT4291 has all of the features offered in the AAT4290, but integrates three switches instead of five. It operates with input voltages ranging from 1.8V to 5.5V which, along with its extremely low operating current, makes it ideal for battery-powered applications. In cases where the input voltage drops below 1.8V, the AAT4290 MOSFETs are protected from entering the linear region of operation by automatically shutting down. In addition, the TTL-compatible EN/SET pin makes the AAT4290 an ideal level-shifted load switch. An optional slew rate controlling feature eliminates in-rush current when a MOSFET is turned on, allowing the AAT4290 to be implemented with a small input capacitor or no capacitor at all, while maintaining isolation between channels. During slewing, the current ramps linearly until it reaches the level required for the output load condition. The proprietary control method works by careful control and monitoring of the MOSFET gate voltage. When the device is switched ON, the gate voltage is quickly increased to the threshold level of the MOSFET. Once at this level, the current begins to slew as the gate voltage is slowly increased until the MOSFET becomes fully enhanced. Once it has reached this point, the gate is quickly increased to the full input voltage and $R_{DS(ON)}$ is minimized.

The ON/OFF state of the five MOSFET switches are controlled by the EN/SET serial data input. An internal control counter is clocked on the rising edge of the EN/SET pin and is decoded into the 32 possible states of the MOSFET (see Table 1). The counter rolls over after 32 clocks and the table repeats. The counter can be clocked at speeds up to 1MHz, but the count value is not latched until clocking has stopped and the EN/SET pin has remained high for approximately 2.6 μ s. The first rising edge of EN/SET enables the AAT4290 and is counted as the first clock. To change states, additional low going clock pulses may be asserted on the EN/SET pin with the resulting change taking effect after the EN/SET pin has remained in a high state for T_{LAT} . The AAT4290 is disabled after the EN/SET pin has transitioned and remained in a logic low state for T_O .

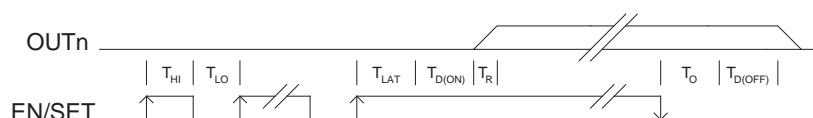
With the exception of three channel power switches, the AAT4291 has a similar function to the AAT4290. The ON/OFF state of the three MOSFET switches are controlled by the EN/SET serial data input. An internal control counter is clocked on the rising edge of the EN/SET pin and is decoded into the eight possible states of the MOSFET (see Table 2). The counter rolls over after eight clocks and the table repeats.

Figure 4 shows the timing diagram.

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I/O Expander Load Switches with Serial Control

Timing Diagram

**Figure 4. Timing Diagram.**

Clock	OUT5	OUT4	OUT3	OUT2	OUT1
1	on	on	on	on	on
2	on	on	on	on	off
3	on	on	on	off	on
4	on	on	on	off	off
5	on	on	off	on	on
6	on	on	off	on	off
7	on	on	off	off	on
8	on	on	off	off	off
9	on	off	on	on	on
10	on	off	on	on	off
11	on	off	on	off	on
12	on	off	on	off	off
13	on	off	off	on	on
14	on	off	off	on	off
15	on	off	off	off	on
16	on	off	off	off	off
17	off	on	on	on	on
18	off	on	on	on	off
19	off	on	on	off	on
20	off	on	on	off	off
21	off	on	off	on	on
22	off	on	off	on	off
23	off	on	off	off	on
24	off	on	off	off	off
25	off	off	on	on	on
26	off	off	on	on	off
27	off	off	on	off	on
28	off	off	on	off	off
29	off	off	off	on	on
30	off	off	off	on	off
31	off	off	off	off	on
32	off	off	off	off	off

Table 1: AAT4290 Output Settings.

Clock	OUT3	OUT2	OUT1
1	on	on	on
2	on	on	off
3	on	off	on
4	on	off	off
5	off	on	on
6	off	on	off
7	off	off	on
8	off	off	off

Table 2: AAT4291 Output Settings.

Applications Information

Thermal Considerations

The AAT4290 is designed to deliver continuous output load currents. Due to its high level of integration, care must be taken in designing for higher load conditions. If greater loads are required, outputs can be tied together to deliver higher power to a given load.

At 25°C ambient, the AAT4290 is capable of dissipating 440mW of power, or 1.14A at 5.0V, for an average current of 228mA per output.

At 85°C ambient, the AAT4290 is capable of dissipating 178mW of power, or 0.72A at 5.0V, for an average current of 145mA per output.

Output Sequencing

If output sequencing is not necessary, then all of the outputs will be switched on simultaneously on the first rising edge of the EN/SET pin. However, if output sequencing is desired, then a series of pulses on the EN/SET pin will accomplish this. Each time a new group of pulses is asserted on EN/SET, the AAT4290/91 internal control is reset. For example, to sequence the outputs in order from OUT5 to OUT1, five clocks bursts are input on the EN/SET pin. From Table 1, the first burst of 16 clocks turns on OUT5. A following burst of 8 clocks (as the counter resets) will add OUT4, followed by 4 clocks to add OUT3, 2 clocks to add OUT2, and 1 clock to add OUT1. Likewise, the outputs can be turned off in any order by adding more clock bursts.

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I/O Expander Load Switches with Serial Control

Applications Circuits

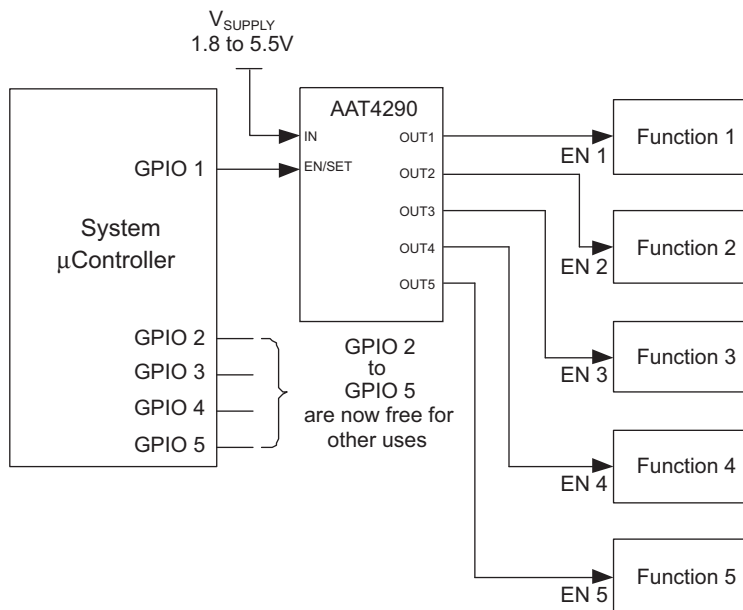


Figure 5: GPIO I/O Expander
(condense five GPIO control lines to one).

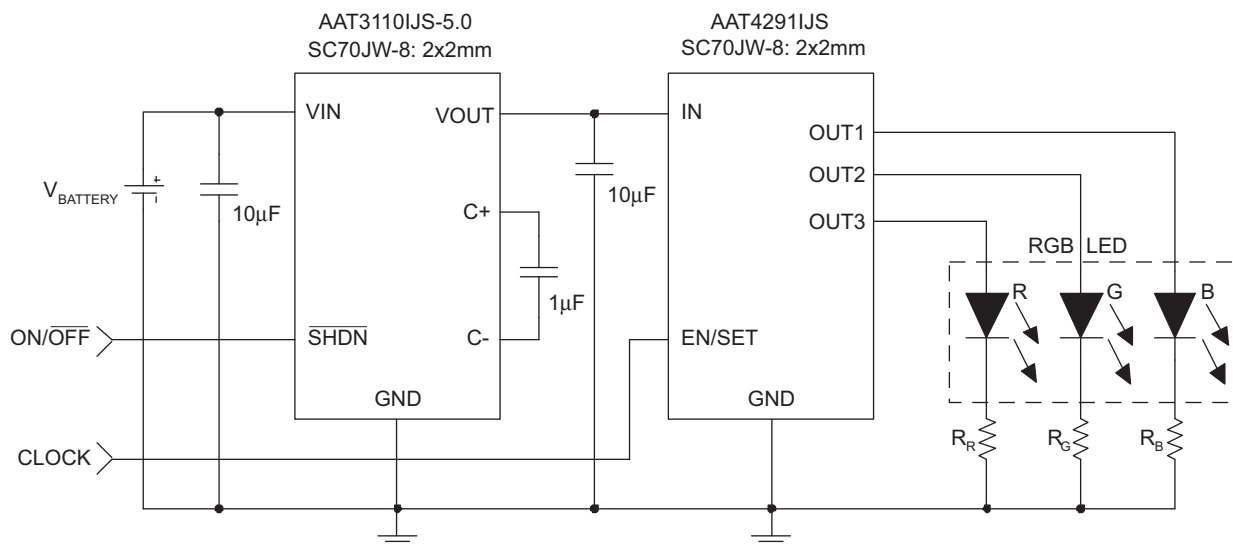


Figure 6: RGB LED Control
(eliminate three discrete MOSFET switches).

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I/O Expander Load Switches with Serial Control

Evaluation Board Description

AAT4290 Evaluation Board

The AAT4290IJS-1-DB3 Evaluation Board is used to test the performance of the AAT4290. This section describes

the evaluation board and its accompanying user interface. In addition, a brief Getting Started section is included to help the user begin operating the evaluation board. A schematic of the complete circuit is shown in Figure 7.

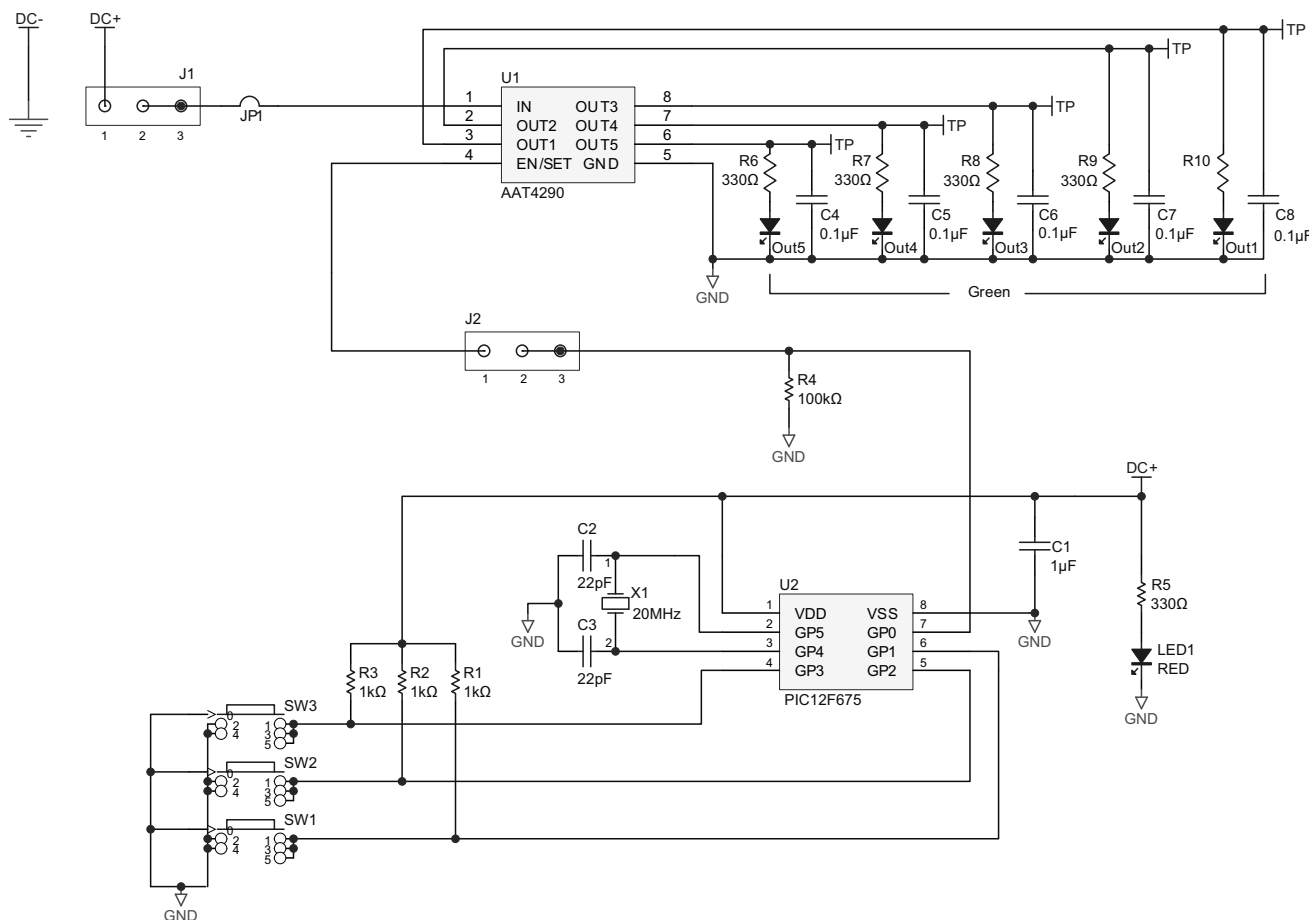


Figure 7: AAT4290IJS-1-DB3 Evaluation Board Schematic.

Getting Started

The AAT4290IJS-1-DB3 evaluation board is typically mounted on a battery pack. The battery pack holds three AAA size, conventional alkaline batteries. A jumper is inline with the battery supply for connecting/disconnecting power. There is an additional jumper labeled ON SRL OFF, which provides access to EN/SET. Ensure that the jumper is in the ON SRL position for normal operation. To apply power to the board, ensure the jumper is at the ON MCU position. The red LED1 should illuminate indicating that power has been connected.

The AAT4290 may be operated from an external power source. The batteries should be removed from the battery pack. External power may be applied to the DC+ and DC- points on the board. The external power source should be set from 1.8V to 5.5V before the AAT4290 is turned on by moving the jumper on J1 to the "ON MCU" position.

There are three buttons on the board (SW1, SW2, and SW3) that enable and disable the ON and OFF state for the five output channels. Once a button (or a combination of buttons) is toggled, the corresponding LED for

AAT4290/4291

I/O Expander Load Switches with Serial Control

OUT1 to OUT5 will turn ON or OFF accordingly, depending on the previous state. This indicates that the selected state has been submitted through the EN/SET line to the AAT4290. Detailed operations are listed in Table 3. Toggling SW1 and SW3 at once, activates the auto-cycling state through the Table 1 "AAT4290 Output Settings". In other words, the microcontroller will submit a burst of edges, pause, and submit another burst of edges and so on. It will start by submitting 31 edges, next submit 30 edges, etc.; next, submit 1 edge and

then start over. All LEDs should blink five times before the sequence of autocycling. By toggling all three buttons together, all LEDs should turn off.

The AAT4290 outputs can be probed via the test points near the output capacitors (C4 to C8).

The evaluation board layer detail is provided in Figures 8 and 9. Table 4 provides the component list for the AAT4290 evaluation board.

Button(s) Pushed	Description
SW1	Toggle on/off of output Channel 1.
SW2	Toggle on/off of output Channel 2.
SW3	Toggle on/off of output Channel 3.
SW1 + SW2	Toggle on/off of output Channel 4.
SW2 + SW3	Toggle on/off of output Channel 5.
SW1 + SW3	Auto cycling. All outputs blinks (on and off) five times and enter binary-increment mode. Auto cycling repeats three times.
SW1 + SW2 + SW3	Reset. All outputs turn off.

Table 3: User Interface Functionality.

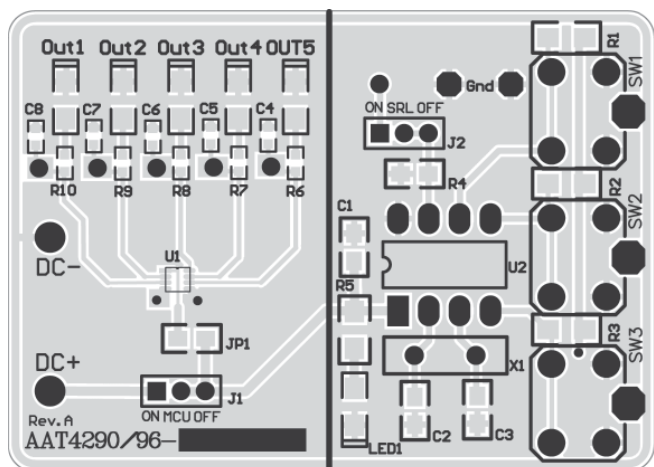


Figure 8: Top Layer (not to scale).

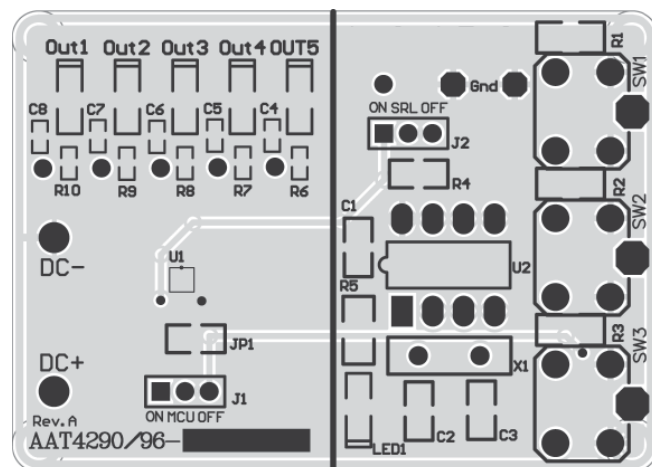


Figure 9: Bottom Layer (not to scale).

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I/O Expander Load Switches with Serial Control

Component	Part#	Description	Manufacturer
U1	AAT4290	I/O Expander Load Switch with Serial Control; SC70JW-8 package	Skyworks
U2	PIC12F675	8-bit CMOS, FLASH-based μ C; 8-Pin PDIP package	Microchip
SW1 – SW3	PTS645TL50	Switch Tact, SPST, 5mm	ITT Industries
R1 – R3	Chip Resistor	1K, 5%, 1/4W; 1206	Vishay
R4	Chip Resistor	100K, 5%, 1/4W; 0805	Vishay
R5	Chip Resistor	330K, 5%, 1/4W; 1206	Vishay
R6-R10	Chip Resistor	330K, 5%, 1/4W; 0603	Vishay
JP1	Chip Resistor	0 Ω , 5%; 0805	Vishay
C1	ECJ-2YB1A105K	1 μ F, 10V, X5R, 10%; 0805	Panasonic-ECG
C2, C3	VJ0805A220KXAA	22pF, 50V, NPO, 10%; 0805	Vishay
C4-C8 (optional)	GRM188R71C104KA01D	0.1 μ F, 16V, 10%; 0603	Murata
J1, J2	PRPN401PAEN	Con. Header, 2mm zip	Sullins Electronics
X1	X439-ND	Quartz crystal 20MHz HC-49US	ECS Inc
LED1	CMD15-21SRC/TR8	Red LED; 1206	Chicago Miniature Lamp
OUT1-OUT5	CMD15-21UGC/TR8	Green LED; 1206	Chicago Miniature Lamp

Table 4: AAT4290 Evaluation Board Component Listing.

AAT4291 Evaluation Board

This section discusses the AAT4291 evaluation board and the application of the AAT4291 as an RGB LED driver. Advanced RGB LED control is realized without having to use multiple discrete MOSFET switches controlled by multiple I/O pins from the system processor. Only one digital I/O pin is needed for complete, independent brightness control of each of the R, G, and B LEDs.

Using RGB LEDs to generate various colors presents unique challenges. Among them is a requirement to pulse width modulate (PWM) three independent LED currents to accurately control the brightness for each LED color. The AAT4291 is well suited for this. Using only one GPIO pin from the system processor, a high PWM rate can be achieved with complete brightness control for each LED.

A schematic of the complete circuit is shown in Figure 10.

Getting Started

The evaluation board comes with a battery pack attached. In this configuration, VIN is supplied from three standard "AAA" alkaline batteries. Under new conditions for the batteries, the input voltage is generally 4.7V ~ 4.8V and falls off depending on the degree of discharge and load conditions. If desired, the batteries can be removed and an independent, DC supply can be used.

There are five buttons on the board. Their functions are as follows:

- SW1: Increments through the eight Output Setting states (Table 2).
- SW2: Increments B_LED duty cycle.
- SW3: Increments G_LED duty cycle.
- SW4: Increments R_LED duty cycle.
- SW5: Brings EN/SET low (shuts down the AAT4291 device).

Notes:

1. Buttons 1 through 4 will automatically increment if held down.
2. Buttons 2 through 4 are set up so that a user can independently control the corresponding R, G, or B LED brightness. This is done by incrementing the PWM duty cycle through the following states: 0%, 25%, 50%, 75%, 100%, 0%, ...

The PIC microcontroller toggles the EN/SET line high and low at 500kHz. The rise and fall times of the EN/SET signal are small relative to the period, so T_{HI} and T_{LO} are roughly 1 μ s (see Figure 10). T_{HI} and T_{LO} depend on the μ C's internal RC oscillator, so the 1 μ s reference is an approximate figure and subject to the precision of the RC oscillator.

Figure 11 shows the typical EN/SET signal.

The evaluation board layer detail is provided in Figures 12 through 14. Table 5 provides the component list for the AAT4290 evaluation board.

AAT4290/4291

I/O Expander Load Switches with Serial Control

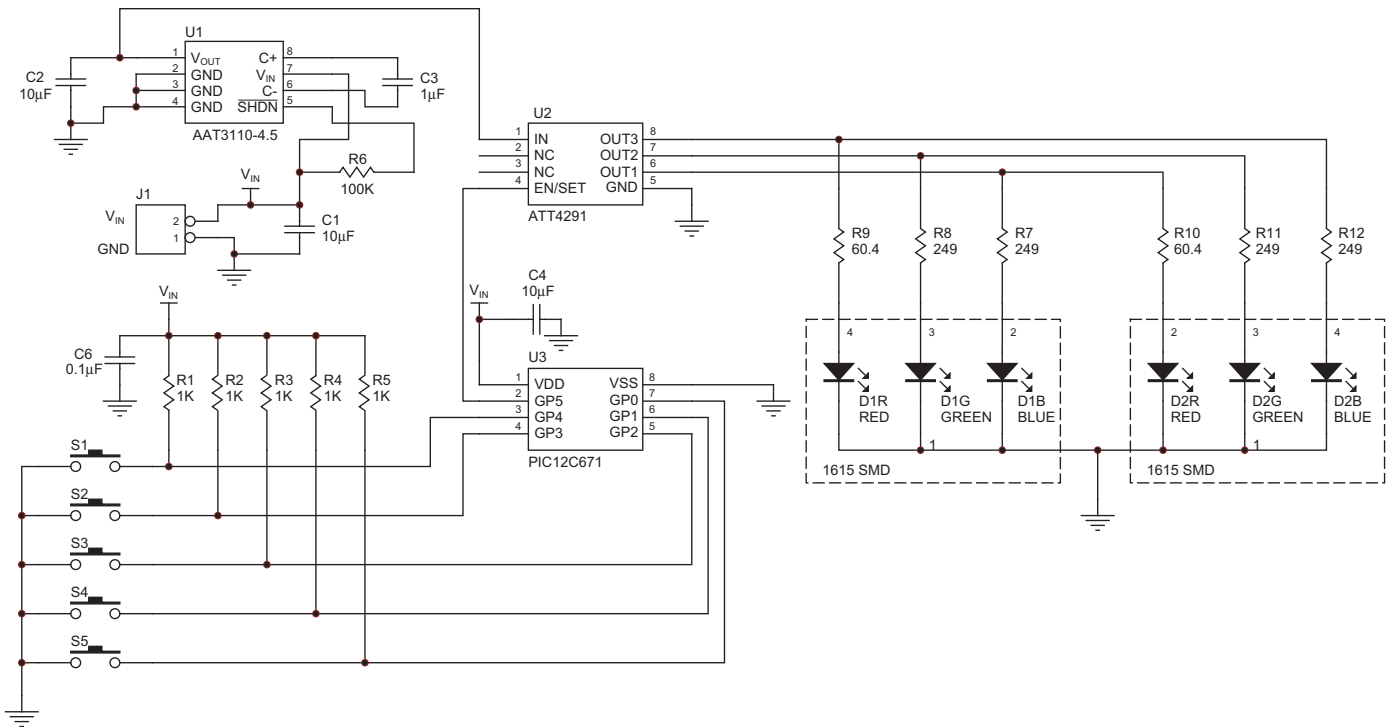


Figure 10: AAT4291IJS-1 Evaluation Board Schematic.

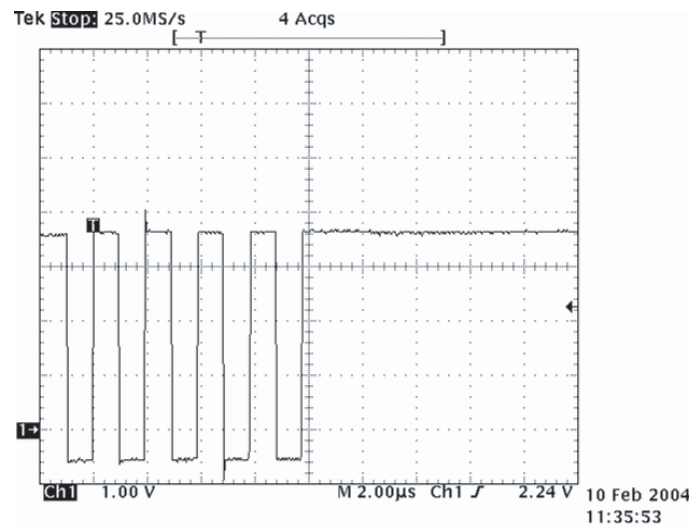


Figure 11: Typical EN/SET Signal.

AAT4290/4291

I/O Expander Load Switches with Serial Control

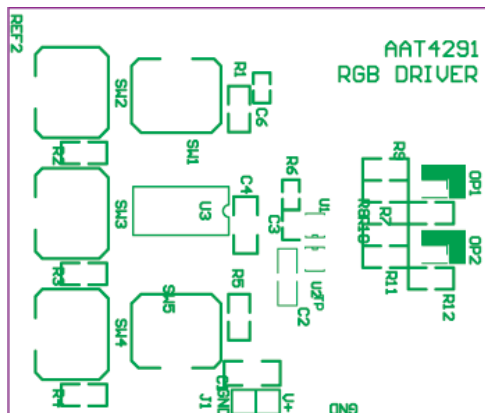


Figure 12: Top Layer Silkscreen (not to scale).

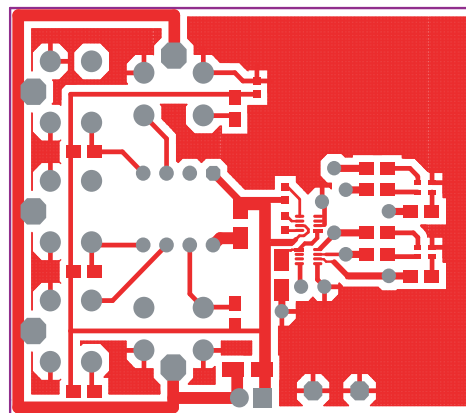


Figure 13: Top Layer (not to scale).

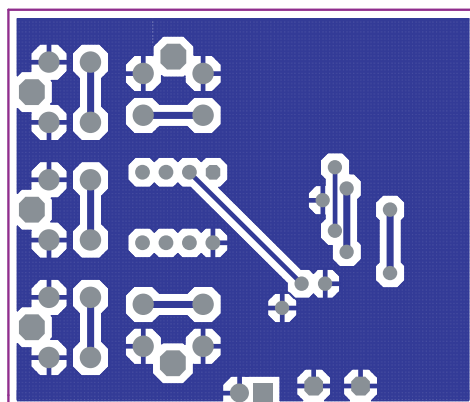


Figure 14: Bottom Layer (not to scale).

Component	Part#	Description	Manufacturer
U1	AAT3110	µPower regulated 4.5V CP; SC70JW-8 package	Skyworks
U2	AAT4291	I/O Expander load switches; SC70JW-8 package	Skyworks
U3	PIC12C671	8-bit CMOSµC; 8-pin PDIP package	Microchip
OP1, OP2	CSLRGB1-1505	RGB LED, common-cathode; 1505 package	CSENG
C1, C2, C4	GRM31CR70J106KA01L	10µF, 6.3V, X7R, 10%; 1206	Murata
C3	ECJ-1VB1A105K	1µF, 10V, X5R, 10%; 0603	Panasonic-ECG
C6	ECJ-1VB1C104K	0.1µF, 16V, X7R, 10%; 0603	Panasonic-ECG
R1 – R5	Chip Resistor	1K, 5%, 1/8W; 0805	Vishay
R6	Chip Resistor	100K, 5%, 1/10W; 0603	Vishay
R7, R12	Chip Resistor	249, 1%, 1/10W; 0805	Vishay
R8, R11	Chip Resistor	249, 1%, 1/10W; 0805	Vishay
R9, R10	Chip Resistor	60.4, 1%, 1/10W; 0805	Vishay
SW1 – SW5	PTS645TL50	Switch Tact, SPST, 5mm	ITT Industries

Table 5: AAT4291 Evaluation Board Component Listing.

AAT4290/4291

I/O Expander Load Switches with Serial Control

Ordering Information

Package	Marking ¹	Part Number (Tape and Reel) ²
SC70JW-8	HSXY	AAT4290IJS-1-T1
SC70JW-8	HCTX	AAT4291IJS-1-T1

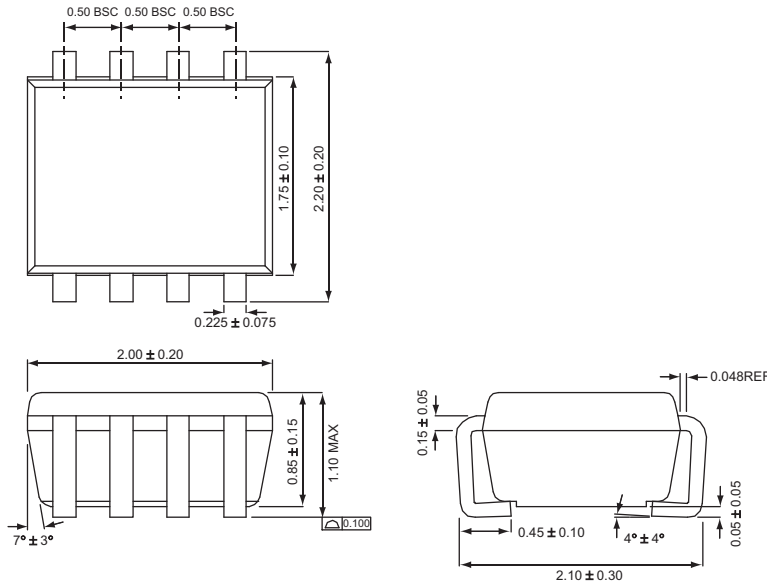


Skyworks Green™ products are compliant with all applicable legislation and are halogen-free.

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

Package Information

SC70JW-8



All dimensions in millimeters.

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

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