General Description

The AAT1150 SwitchReg™ is a member of AnalogicTech's Total Power Management IC™ (TPMIC™) product family. The step-down switching converter is ideal for applications where high efficiency, small size, and low ripple are critical. Able to deliver 1A with internal power MOSFETs, the current-mode controlled IC provides high efficiency using synchronous rectification. Fully internally compensated, the AAT1150 simplifies system design and lowers external parts count.

The AAT1150 is available in an MSOP-8 package and is rated over the -40°C to +85°C temperature range.

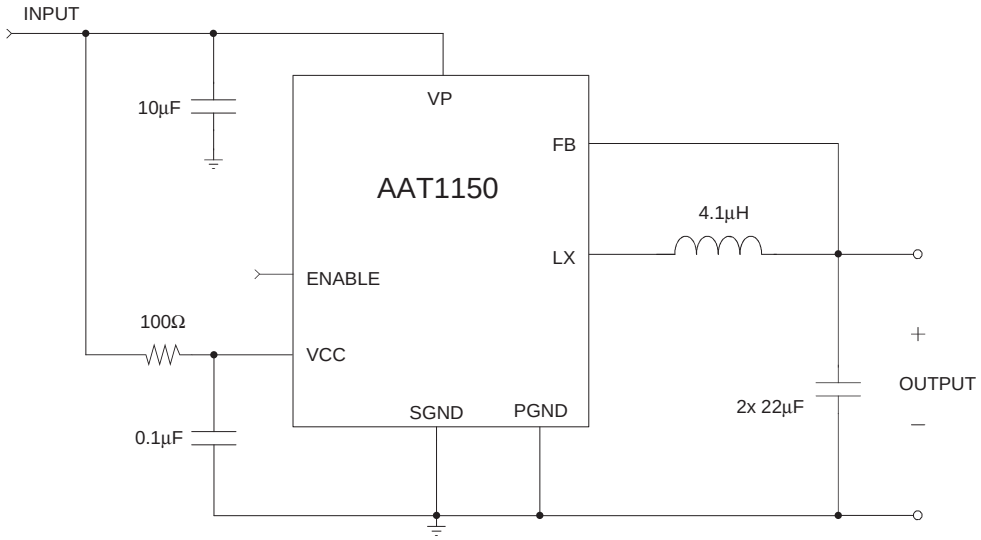
Features

- V_{IN} Range: 2.7V to 5.5V
- Up to 95% Efficiency
- 110mΩ $R_{DS(ON)}$ MOSFET Switch
- <1.0µA of Shutdown Current
- 1MHz Switching Frequency
- Fixed or Adjustable V_{OUT}: 1.0V to 4.2V
- High Initial Accuracy: ±1%
- 1.0A Peak Current
- Integrated Power Switches
- Synchronous Rectification
- Internally Compensated Current Mode Control
- Constant PWM Mode for Low Output Ripple
- Internal Soft Start
- Current Limit Protection
- Over-Temperature Protection
- MSOP-8 package
- -40°C to +85°C Temperature Range

Applications

- Cable/DSL Modems
- Computer Peripherals
- High Efficiency Conversion From 5V or 3.3V Supply
- Network Cards
- Set-Top Boxes

Typical Application

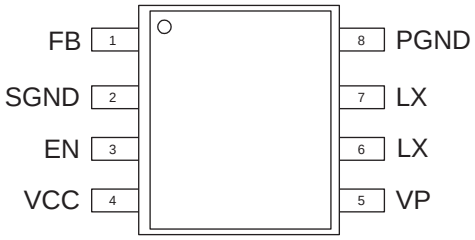


Pin Descriptions

Pin #	Symbol	Function
1	FB	Feedback input pin. This pin must be connected to the converter's output. It is used to set the output of the converter to regulate to the desired value.
2	SGND	Signal ground.
3	EN	Enable input pin. When connected high, the AAT1150 is in normal operation. When connected low, it is powered down. This pin should not be left floating.
4	VCC	Power supply. It supplies power for the internal circuitry.
5	VP	Input supply voltage for converter power stage.
6, 7	LX	Inductor connection pins. These pins should be connected to the output inductor. Internally, Pins 6 and 7 are connected to the drains of the P-channel switch and N-channel synchronous rectifier.
8	PGND	Power ground return for the output stage.

Pin Configuration

MSOP-8
(Top View)



Absolute Maximum Ratings[1]

T_A = 25°C, unless otherwise noted.

Symbol	Description	Value	Units
V_{CC}, V_P	V_{CC}, V_P to GND	6	V
V_{LX}	LX to GND	-0.3 to V_P+0.3	V
V_{FB}	FB to GND	-0.3 to V_{CC}+0.3	V
V_{EN}	EN to GND	-0.3 to 6	V
T_J	Operating Junction Temperature Range	-40 to 150	°C
V_{ESD}	ESD Rating[2] - HBM	3000	V

Thermal Characteristics

Symbol	Description	Value	Units
Θ_{JA}	Maximum Thermal Resistance (MSOP-8)[3]	150	°C/W
P_D	Maximum Power Dissipation (MSOP-8, T_A = 25°C)[3, 4]	667	mW

Recommended Operating Conditions

Symbol	Description	Rating	Units
T	Ambient Temperature Range	-40 to +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. 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 into each pin.
3. Mounted on a demo board.
4. Derate 6.7mW/°C above 25°C.

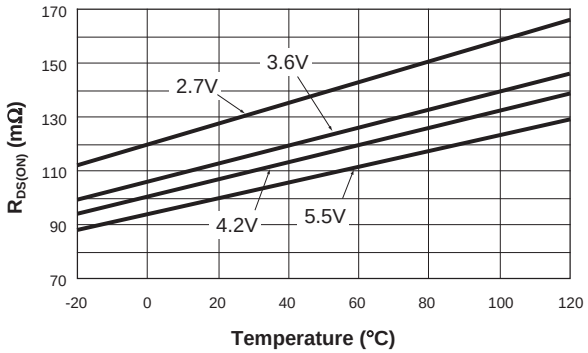
Electrical Characteristics

V_{IN} = V_{CC} = V_P = 5V, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = 25°C.

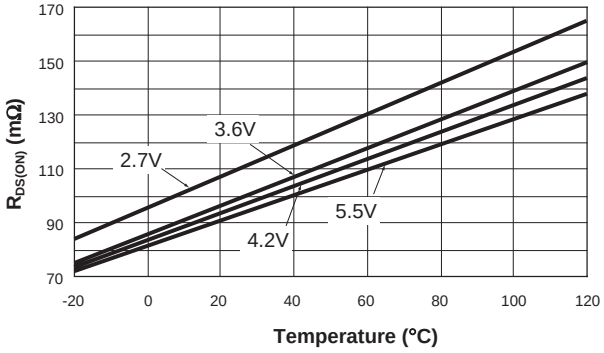
Symbol	Description	Conditions	Min	Typ	Max	Units
V_{IN}	Input Voltage Range		2.7		5.5	V
V_{OUT}	Output Voltage Tolerance	V_{IN} = V_{OUT} + 0.3 to 5.5V, I_{OUT} = 0 to 1A	-4.0		4.0	%
ΔV_{OUT} (V_{OUT}*ΔV_{IN})	Load Regulation	V_{IN} = 4.2V, I_{LOAD} = 0 - 1A		3.0		%
$\Delta V_{OUT}/V_{OUT}$	Line Regulation	V_{IN} = 2.7 to 5.5V		0.2		%/V
V_{UVLO}	Under-Voltage Lockout	V_{IN} Rising			2.5	V
		V_{IN} Falling	1.2			
$V_{UVLO(HYS)}$	Under-Voltage Lockout Hysteresis			250		mV
I_Q	Quiescent Supply Current	No Load, V_{FB} = 0		160	300	µA
I_{SHDN}	Shutdown Current	V_{EN} = 0V, V_{IN} = 5.5V			1.0	µA
I_{LIM}	Current Limit	T_A = 25°C	1.2			A
$R_{DS(ON)H}$	High Side Switch On Resistance	T_A = 25°C		110	150	mΩ
$R_{DS(ON)L}$	Low Side Switch On Resistance	T_A = 25°C		100	150	mΩ
η	Efficiency	V_{IN} = 5V, V_{OUT} = 3.3V, I_{OUT} = 600mA		93		%
$V_{EN(L)}$	Enable Low Voltage	V_{IN} = 2.7 to 5.5V			0.6	V
$V_{EN(H)}$	Enable High Voltage	V_{IN} = 2.7 to 5.5V	1.4			V
I_{EN}	Enable Pin Leakage Current	V_{EN} = 5.5V			1.0	µA
F_{OSC}	Oscillator Frequency	T_A = 25°C	700	1000	1200	kHz
T_{SD}	Over-Temperature Shutdown Threshold			140		°C
T_{HYS}	Over-Temperature Shutdown Hysteresis			15		°C

Typical Characteristics

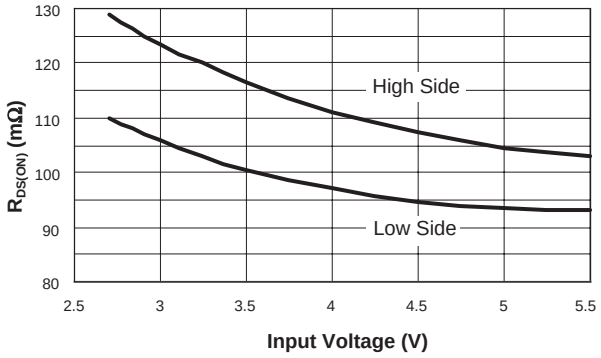
High Side $R_{DS(ON)}$ vs. Temperature



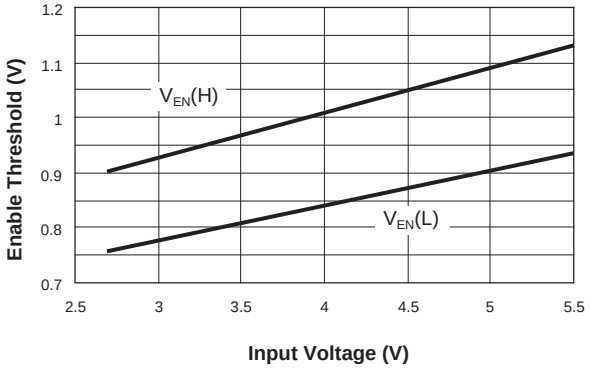
Low Side $R_{DS(ON)}$ vs. Temperature



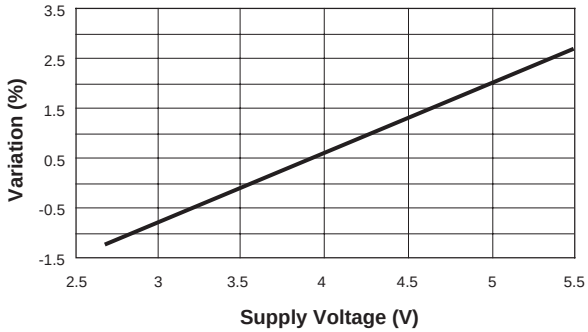
$R_{DS(ON)}$ vs. Input Voltage



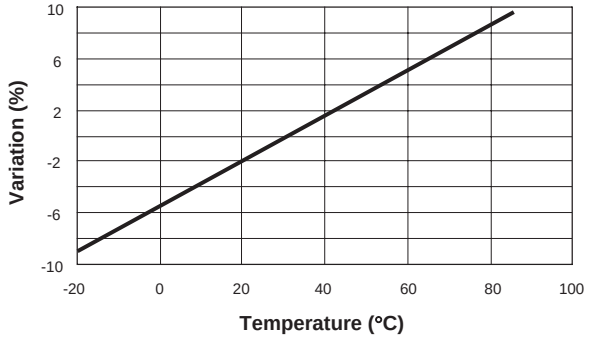
Enable Threshold vs. Input Voltage



Oscillator Frequency Variation vs. Supply Voltage

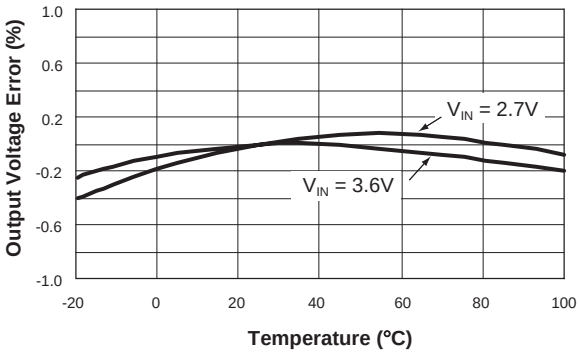


Oscillator Frequency Variation vs. Temperature
(V_{IN} = 3.6V)

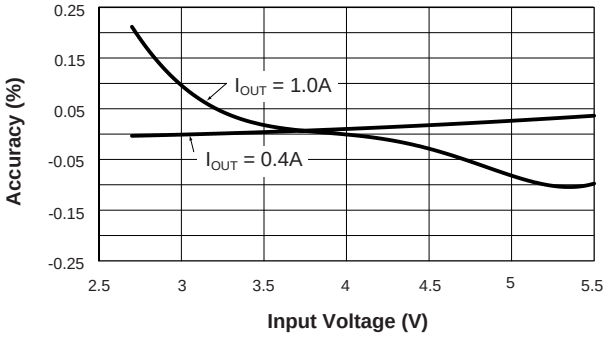


Typical Characteristics

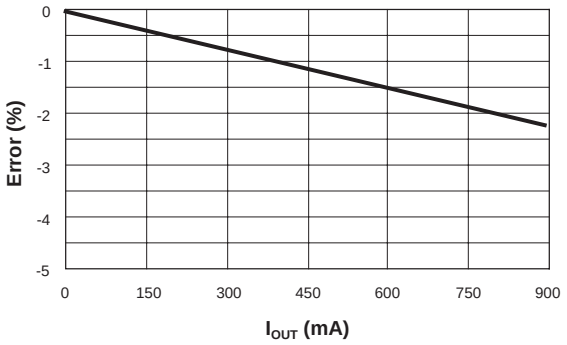
Output Voltage vs. Temperature
(I_{OUT} = 900mA; V_{OUT} = 1.5V)



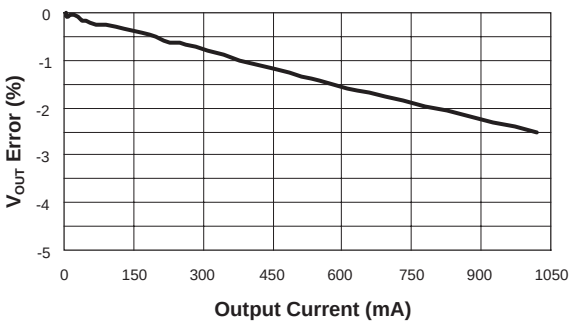
Line Regulation
(V_{OUT} = 1.5V)



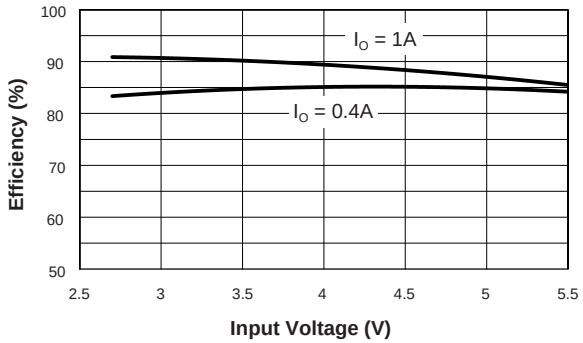
Load Regulation
(V_{OUT} = 1.5V; V_{IN} = 3.6V)



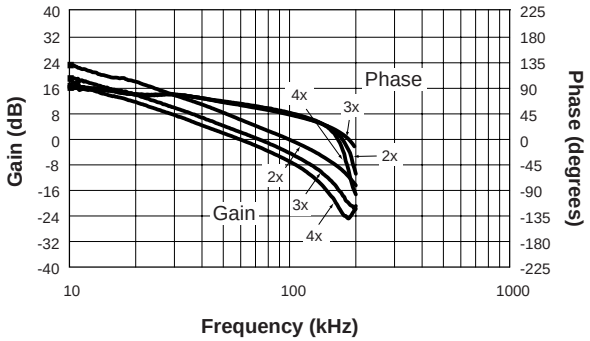
Load Regulation
(V_{OUT} = 3.3V; V_{IN} = 5.0V)



Efficiency vs. Input Voltage
(V_{OUT} = 1.5V)

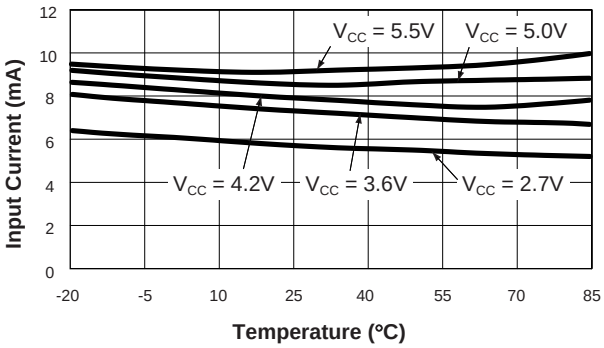


Loop Gain and Phase vs. Output Capacitor
(V_{IN} = 3.6V; I_{OUT} = 0.3A; C_O = 22µF)

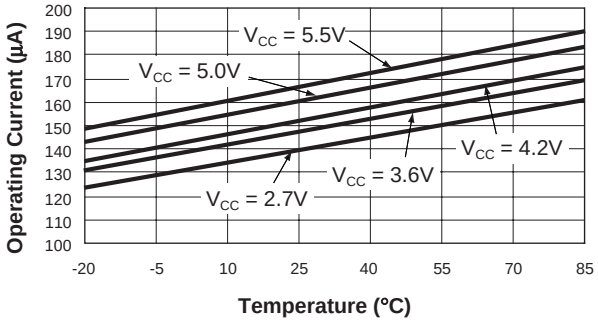


Typical Characteristics

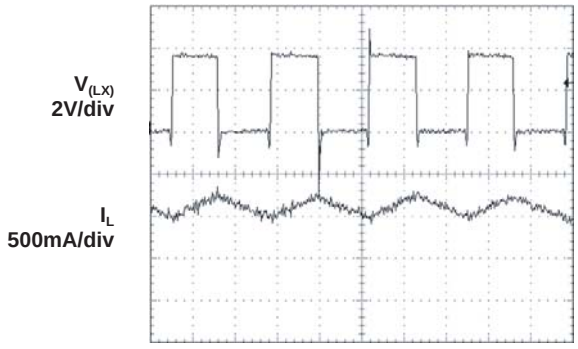
No Load Input Current vs. Temperature
(V_{CC} = V_P)



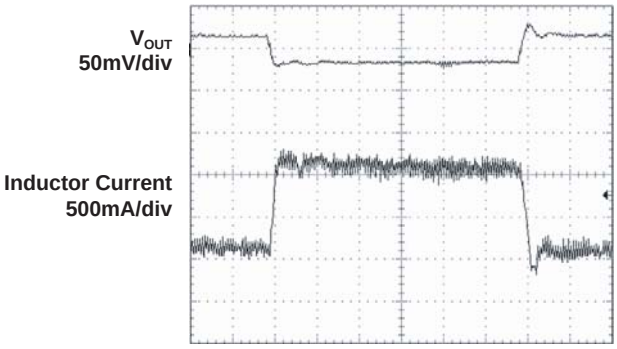
Non-Switching I_Q vs. Temperature
(FB = 0V; V_P = V_{CC})



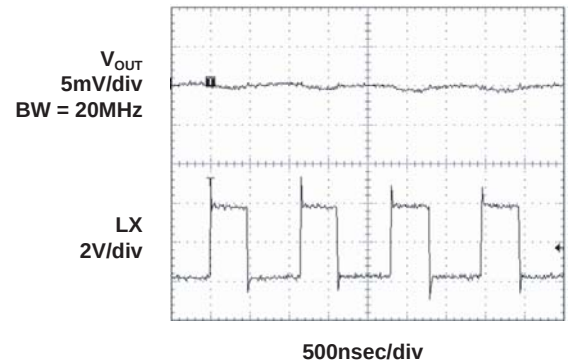
Switching Waveform
(V_{IN} = 3.6V; V_{OUT} = 1.5V; I_{OUT} = 1.2A)



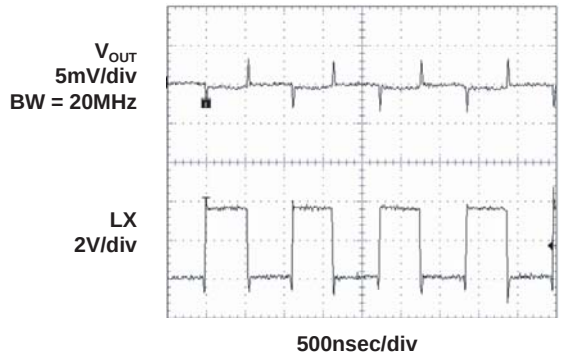
Transient Response
(V_{IN} = 3.6V; V_{OUT} = 1.5V; I_{LOAD} = 0.25 to 1.2A)



Output Ripple
(V_{IN} = 3.6V; V_{OUT} = 1.5V; I_{OUT} = 0A)

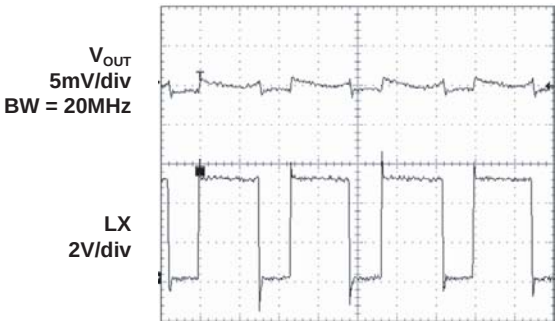


Output Ripple
(V_{IN} = 3.6V; V_{OUT} = 1.5V; I_{OUT} = 1A)

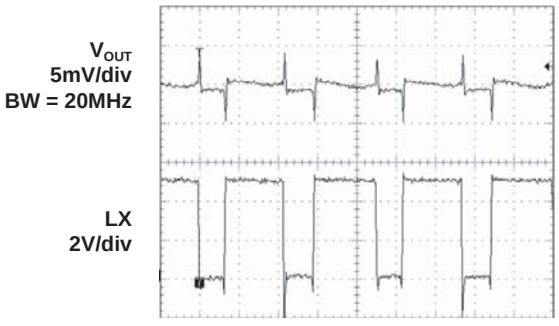


Typical Characteristics

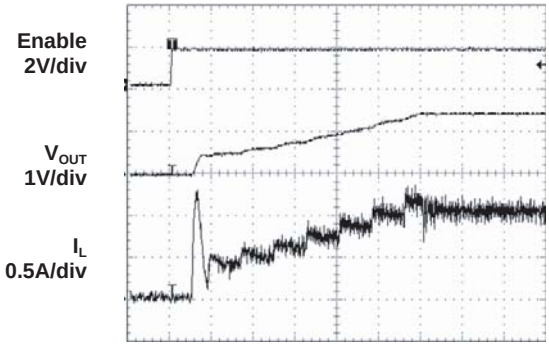
Output Ripple
(V_{IN} = 5.0V; V_{OUT} = 3.3V; I_{OUT} = 0A)



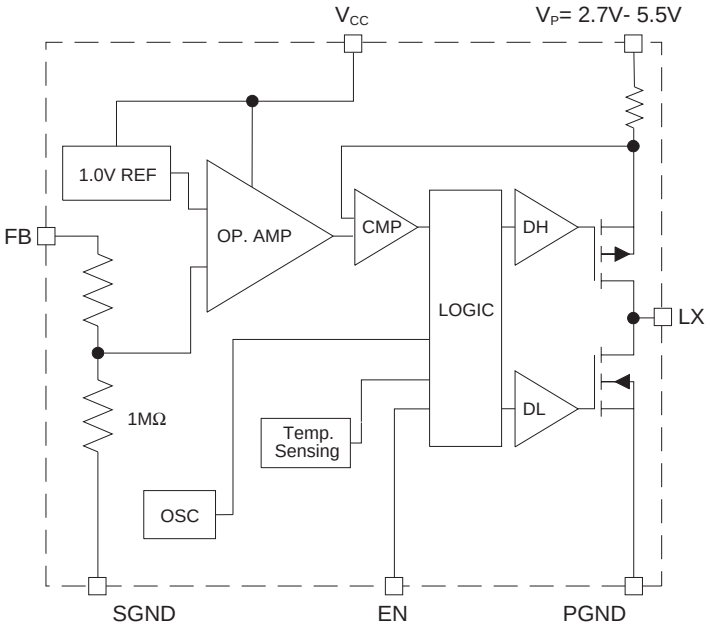
Output Ripple
(V_{IN} = 5.0V; V_{OUT} = 3.3V; I_{OUT} = 1A)



Inrush Limit
(V_{IN} = 3.6V; V_{OUT} = 1.5V; I_L = 1A)



Functional Block Diagram



Applications Information

Control Loop

The AAT1150 is a peak current mode buck converter. The inner wide bandwidth loop controls the peak current of the output inductor. The output inductor current is sensed through the P-channel MOSFET (high side) and is also used for short-circuit and overload protection. A fixed slope compensation signal is added to the sensed current to maintain stability. The loop appears as a voltage-programmed current source in parallel with the output capacitor.

The voltage error amplifier output programs the current loop for the necessary inductor current to force a constant output voltage for all load and line conditions. The feedback resistive divider is internal, dividing the output voltage to the error amplifier reference voltage of 1.0V. The error amplifier does not have a large DC gain typical of most error amplifiers. This eliminates the need for external compensation components while still providing sufficient DC loop gain for load regulation. The crossover frequency and phase margin are set by the output capacitor value only.

Soft Start/Enable

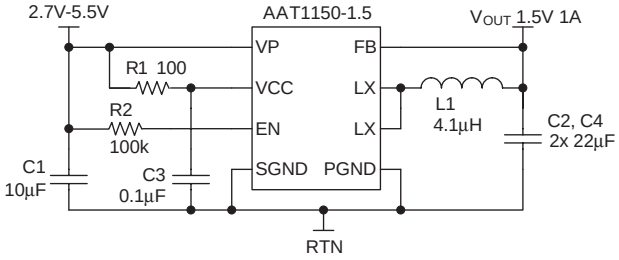
Soft start increases the inductor current limit point in discrete steps when the input voltage or enable input is applied. It limits the current surge seen at the input and eliminates output voltage overshoot. The enable input, when pulled low, forces the AAT1150 into a low power, non-switching state. The total input current during shutdown is less than 1µA.

Power and Signal Source

Separate small signal ground and power supply pins isolate the internal control circuitry from the noise associated with the output MOSFET switching. The low pass filter R1 and C3 in schematic Figures 1 and 2 filters the noise associated with the power switching.

Current Limit and Over-Temperature Protection

For overload conditions, the peak input current is limited. Figure 3 displays the VI current limit characteristics. As load impedance decreases and the output voltage falls closer to zero, more power is dissipated internally, raising the device temperature. Thermal protection completely disables switching when internal dissipation becomes excessive, protecting the device from damage. The junction over-temperature threshold is 140°C with 15°C of hysteresis.



C1 Murata 10µF 6.3V X5R GRM42-6X 5R106K6.3
C2, C4 MuRata 22µF 6.3V GRM21BR60J226ME39L 0805 X5R
L1 Sumida CDRH5D18-4R 1µH

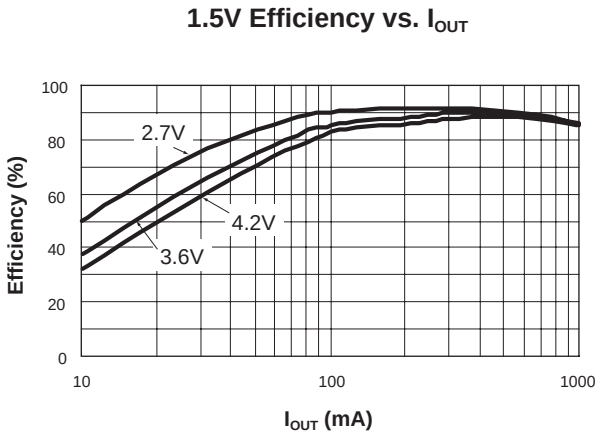
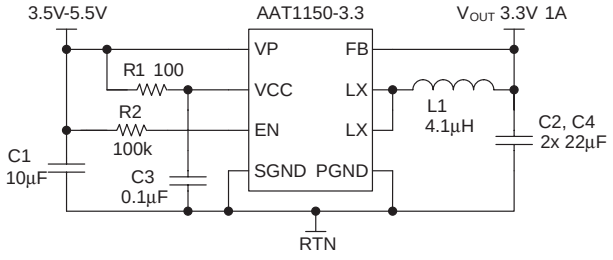


Figure 1: Lithium-Ion to 1.5V Converter.



C1 Murata 10µF 6.3V X5R GRM42-6X 5R106K6.3
C2, C4 MuRata 22µF 6.3V GRM21BR60J226ME39L X5R 0805
L1 Sumida CDRH5D18-4R 1µH

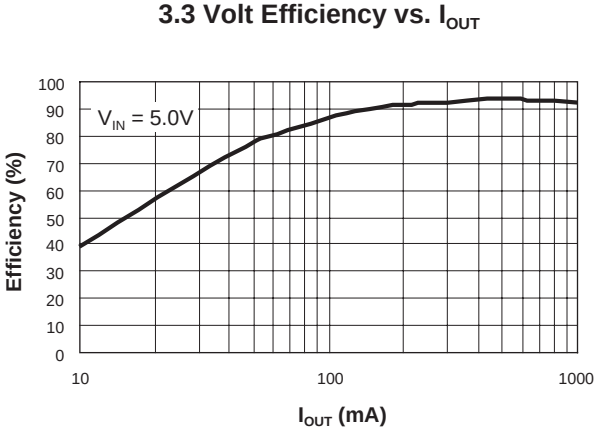


Figure 2: 5V Input to 3.3V Output Converter.

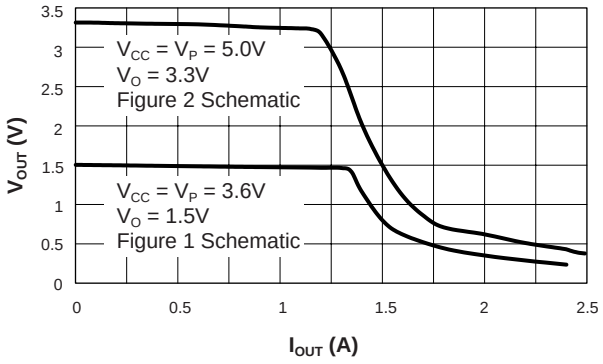


Figure 3: Current Limit Characteristic.

Inductor

The output inductor is selected to limit the ripple current to some predetermined value, typically 20% to 40% of the full load current at the maximum input voltage. Manufacturer's specifications list both the inductor DC current rating, which is a thermal limitation, and the peak current rating, which is determined by the saturation characteristics. The inductor should not show any appreciable saturation under normal load conditions. During overload and short-circuit conditions, the average current in the inductor can meet or exceed the I_{LIMIT} point of the AAT1150 without affecting converter performance. Some inductors may have sufficient peak and average current ratings yet result in excessive losses due to a high DCR. Always consider the losses associated with the DCR and its effect on the total converter efficiency when selecting an inductor.

For a 1.0A load and the ripple set to 30% at the maximum input voltage, the maximum peak-to-peak ripple current is 300mA. The inductance value required is 3.9µH.

$$L = \frac{V_{OUT}}{I_O \cdot k \cdot F} \cdot \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

$$L = \frac{1.5V}{1.0A \cdot 0.3 \cdot 830kHz} \cdot \left(1 - \frac{1.5V}{4.2V}\right)$$

$$L = 3.9\mu H$$

The factor "k" is the fraction of full load selected for the ripple current at the maximum input voltage. The corresponding inductor RMS current is:

$$I_{RMS} = \sqrt{\left(I_o^2 + \frac{\Delta I^2}{12}\right)} \approx I_o = 1.0A$$

ΔI is the peak-to-peak ripple current which is fixed by the inductor selection above. For a peak-to-peak current of 30% of the full load current, the peak current at full load will be 115% of the full load. The 4.1µH inductor selected from the Sumida CDRH5D18 series has a 57mΩ DCR and a 1.95A DC current rating. At full load, the inductor DC loss is 57mW which amounts to a 3.8% loss in efficiency.

Input Capacitor

The primary function of the input capacitor is to provide a low impedance loop for the edges of pulsed current drawn by the AAT1150. A low ESR/ESL ceramic capacitor is ideal for this function. To minimize stray inductance, the capacitor should be placed as closely as possible to the IC. This keeps the high frequency content of the input current localized, minimizing radiated and conducted EMI while facilitating optimum performance of the AAT1150. Ceramic X5R or X7R capacitors are ideal for this function. The size required will vary depending on the load, output voltage, and input voltage source impedance characteristics. A typical value is around 10µF. The input capacitor RMS

current varies with the input voltage and the output voltage. The equation for the RMS current in the input capacitor is:

$$I_{RMS} = I_O \cdot \sqrt{\frac{V_O}{V_{IN}} \cdot \left(1 - \frac{V_O}{V_{IN}}\right)}$$

The input capacitor RMS ripple current reaches a maximum when V_{IN} is two times the output voltage where it is approximately one half of the load current. Losses associated with the input ceramic capacitor are typically minimal and are not an issue. Proper placement of the input capacitor can be seen in the reference design layout shown in Figures 4 and 5.

Output Capacitor

Since there are no external compensation components, the output capacitor has a strong effect on loop stability. Larger output capacitance will reduce the crossover frequency with greater phase margin. For the 1.5V 1.0A design using the 4.1µH inductor, two 22µF capacitors provide a stable output. In addition to assisting stability, the output capacitor limits the output ripple and provides holdup during large load transitions.

The output capacitor RMS ripple current is given by:

$$I_{RMS} = \frac{1}{2 \cdot \sqrt{3}} \cdot \frac{V_{OUT} \cdot (V_{IN} - V_{OUT})}{L \cdot F \cdot V_{IN}}$$

For a ceramic capacitor, the dissipation due to the RMS current of the capacitor is not a concern. Tantalum capacitors, with sufficiently low ESR to meet output voltage ripple requirements, also have an RMS current rating much greater than that actually seen in this application.

Adjustable Output

For applications requiring an output other than the fixed outputs available, the 1V version can be programmed externally (see Figure 6). Resistors R3 and R4 force the output to regulate higher than 1V. R4 should be 100 times less than the internal 1mΩ resistance of the FB pin. Once R4 is selected, R3 can be calculated. For a 1.25V output with R4 set to 10kΩ, R3 is 2.55kΩ.

$$R3 = (V_O - 1) \cdot R4 = 0.25 \cdot 10.0k\Omega = 2.55k\Omega$$

Layout Considerations

Figures 4 and 5 display the suggested PCB layout for the AAT1150. The most critical aspect of the layout is the placement of the input capacitor C1. For proper operation, C1 must be placed as closely as possible to the AAT1150.

Thermal Calculations

There are two types of losses associated with the AAT1150 output switching MOSFET: switching losses and conduction losses. Conduction losses are associated with the $R_{DS(ON)}$ characteristics of the output switching device. At full load, assuming continuous conduction mode (CCM), a simplified form of the total losses is:

$$P_{LOSS} = \frac{I_O^2 \cdot (R_{DSON(H)} \cdot V_O + R_{DSON(L)} \cdot (V_{IN} - V_O))}{V_{IN}} + t_{sw} \cdot F \cdot I_O \cdot V_{IN} + I_Q \cdot V_{IN}$$

Once the total losses have been determined, the junction temperature can be derived from the Θ_{JA} for the MSOP-8 package.

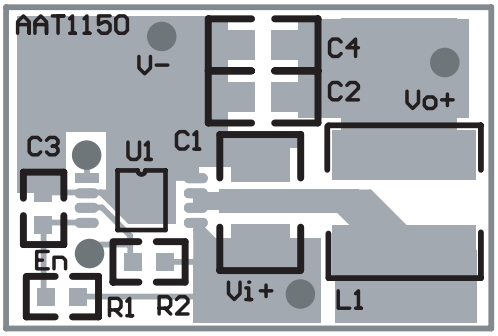


Figure 4: AAT1150 Layout Top Layer.

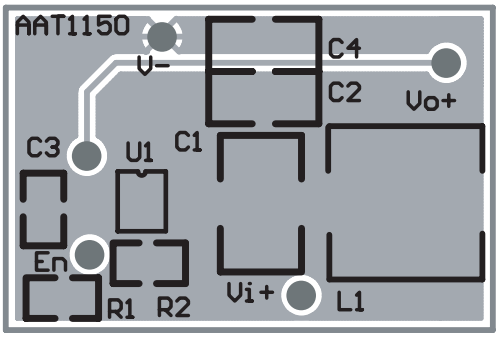
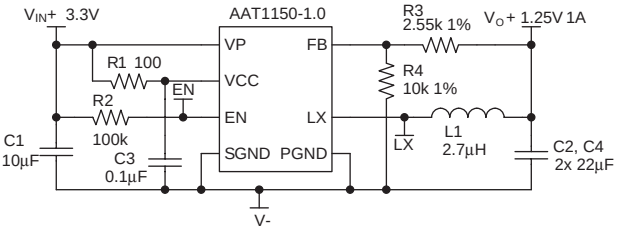


Figure 5: AAT1150 Layout Bottom Layer.



C1 Murata 10µF 6.3V X5R GRM42-6X 5R106K6.3
C2, C4 MuRata 22µF 6.3V GRM21BR60J226ME39L X5R 0805
L1 Sumida CDRH4D28-2R7µH

Figure 6: 3.3V to 1.25V Converter (Adjustable Output).

Design Example

Specifications

I_{OUT} = 1.0A

I_{RIPPLE} = 30% of Full Load at Max V_{IN}

V_{OUT} = 1.5V

V_{IN} = 2.7V to 4.2V (3.6V nominal)

F_s = 830kHz

Maximum Input Capacitor Ripple

$$I_{RMS} = I_O \cdot \sqrt{\frac{V_O}{V_{IN}} \cdot \left(1 - \frac{V_O}{V_{IN}}\right)} = \frac{I_O}{2} = 0.5A_{RMS},\ V_{IN} = 2 \times V_O$$

$$P = ESR_{COUT} \cdot I_{RMS}^2 = 5m\Omega \cdot 0.5^2\ A = 1.25mW$$

Inductor Selection

$$L = \frac{V_{OUT}}{I_O \cdot k \cdot F} \cdot \left(1 - \frac{V_{OUT}}{V_{IN}}\right) = \frac{1.5V}{1.0A \cdot 0.3 \cdot 830kHz} \cdot \left(1 - \frac{1.5V}{4.2V}\right) = 3.9\mu H$$

Select Sumida inductor CDRH5D18, 4.1µH, 57mΩ, 2.0mm height.

$$\Delta I = \frac{V_O}{L \cdot F} \cdot \left(1 - \frac{V_O}{V_{IN}}\right) = \frac{1.5V}{4.1\mu H \cdot 830kHz} \cdot \left(1 - \frac{1.5V}{4.2V}\right) = 280mA$$

$$I_{PK} = I_{OUT} + \frac{\Delta I}{2} = 1.0A + 0.14A = 1.14A$$

$$P = I_O^2 \cdot DCR = 57mW$$

Output Capacitor Dissipation

$$I_{RMS} = \frac{1}{2 \cdot \sqrt{3}} \cdot \frac{V_{OUT} \cdot (V_{IN} - V_{OUT})}{L \cdot F \cdot V_{IN}} = \frac{1}{2 \cdot \sqrt{3}} \cdot \frac{1.5V \cdot (4.2V - 1.5V)}{4.1\mu H \cdot 830kHz \cdot 4.2V} = 82mA_{RMS}$$

$$P_{ESR} = ESR_{COUT} \cdot I_{RMS}^2 = 5m\Omega \cdot 0.082^2 A = 33\mu W$$

AAT1150 Dissipation

$$P = \frac{I_O^2 \cdot (R_{DSON(H)} \cdot V_O + R_{DSON(L)} \cdot (V_{IN} - V_O))}{V_{IN}} + (t_{sw} \cdot F \cdot I_O + I_Q) \cdot V_{IN}$$

$$= \frac{(0.14\Omega \cdot 1.5V + 0.145\Omega \cdot (3.6V - 1.5V))}{3.6V} + (20nsec \cdot 830kHz \cdot 1.0A + 0.3mA) \cdot 3.6V = 0.203W$$

$$T_{J(MAX)} = T_{AMB} + \Theta_{JA} \cdot P_{LOSS} = 85°C + 150°C/W \cdot 0.203W = 115°C$$

Table 1: Surface Mount Inductors.

Manufacturer	Part Number	Value	Max DC Current	DCR	Size (mm) L × W × H	Type
TaiyoYuden	NPO5DB4R7M	4.7µH	1.4A	0.038	5.9 × 6.1 × 2.8	Shielded
Toko	A914BYW-3R5M-D52LC	3.5µH	1.34A	0.073	5.0 × 5.0 × 2.0	Shielded
Sumida	CDRH5D28-4R2	4.2µH	2.2A	0.031	5.7 × 5.7 × 3.0	Shielded
Sumida	CDRH5D18-4R1	4.1µH	1.95A	0.057	5.7 × 5.7 × 2.0	Shielded
MuRata	LQH55DN4R7M03	4.7µH	2.7A	0.041	5.0 × 5.0 × 4.7	Non-Shielded
MuRata	LQH66SN4R7M03	4.7µH	2.2A	0.025	6.3 × 6.3 × 4.7	Shielded

Table 2: Surface Mount Capacitors.

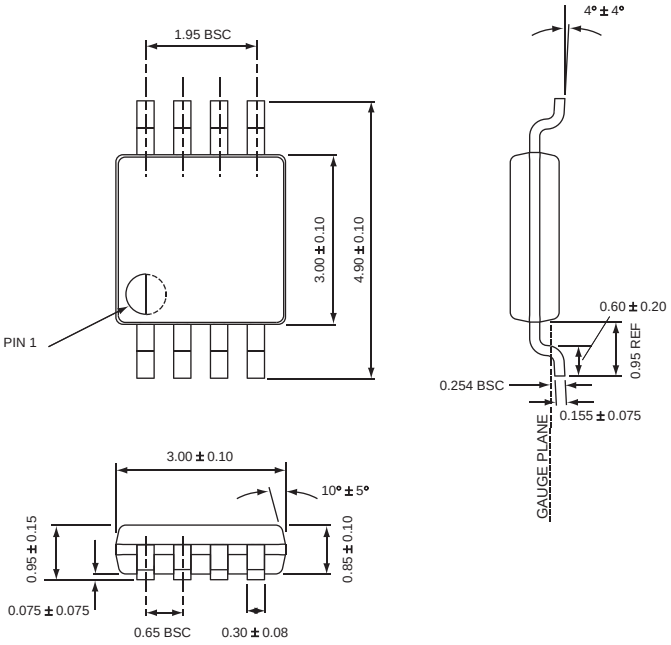
Manufacturer	Part Number	Value	Voltage	Temp. Co.	Case
MuRata	GRM40 X5R 106K 6.3	10µF	6.3V	X5R	0805
MuRata	GRM42-6 X5R 106K 6.3	10µF	6.3V	X5R	1206
MuRata	GRM21BR60J226ME39L	22µF	6.3V	X5R	0805
MuRata	GRM21BR60J106ME39L	10µF	6.3V	X5R	0805

Ordering Information

Output Voltage	Package	Marking	Part Number (Tape and Reel)
1.0V (Adj $V_{OUT} \geq 1.0V$)	MSOP-8	JZXYY	**AAT1150IKS-1.0-T1**
1.5V	MSOP-8	HYXYY	**AAT1150IKS-1.5-T1**
1.8V	MSOP-8	KAXYY	**AAT1150IKS-1.8-T1**
2.5V	MSOP-8	KCXYY	**AAT1150IKS-2.5-T1**
3.3V	MSOP-8	HZXYY	**AAT1150IKS-3.3-T1**

Package Information

MSOP-8



All dimensions in millimeters.

1. XYY = assembly and date code.
2. Sample stock is held on part numbers listed in **bold**. Contact local sales office for custom options.

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