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AAT1156
1MHz 700mA Step-Down DC-DC Converter

SwitchReg™

General Description

The AAT1156 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 is required over the full range of load conditions. The 2.7V to 5.5V input voltage range makes the AAT1156 ideal for single-cell lithium-ion/polymer battery applications. Capable of more than 700mA with internal MOSFETs, the current-mode controlled IC provides high efficiency over a wide operating range. Fully integrated compensation simplifies system design and lowers external parts count.

The AAT1156 is available in the 16-pin 3x3mm QFN package and is rated over the -40°C to +85°C temperature range.

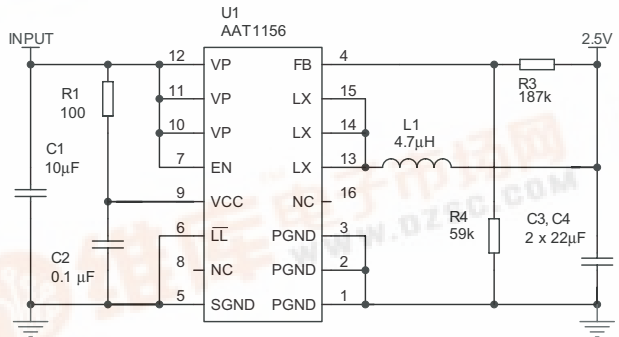
Features

- V_{IN} Range: 2.7 to 5.5 Volts
- Up to 95% Efficiency
- 110mΩ $R_{DS(ON)}$ Internal Switches
- <1µA Shutdown Current
- 1MHz Step-Down Switching Frequency
- Fixed or Adjustable $V_{OUT} \geq 0.8V$
- Integrated Power Switches
- Current Mode Operation
- Internal Compensation
- Stable with Ceramic Capacitors
- Internal Soft Start
- Over-Temperature Protection
- Current Limit Protection
- 16-Pin QFN 3x3mm Package
- -40°C to +85°C Temperature Range

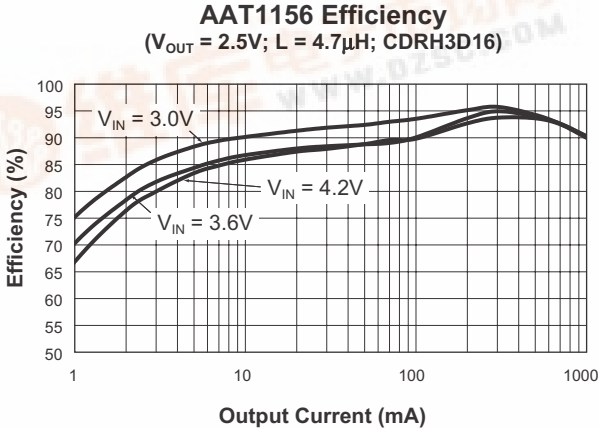
Applications

- Cellular Phones
- Digital Cameras
- MP3 Players
- Notebook Computers
- PDAs
- Wireless Notebook Adapters

Typical Application



C1 Murata 10µF 6.3V X5R GRM42-6X5R106K6.3
C3-C4 MuRata 22µF 6.3V GRM21BR60J226ME39L X5R 0805
L1 Sumida CDRH3D16-4R7NC



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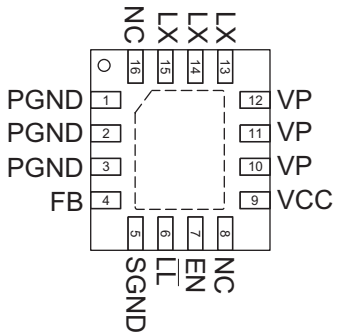
Pin Descriptions

Pin #	Symbol	Function
1, 2, 3	PGND	Main power ground return pin. Connect to the output and input capacitor return. (See board layout rules.)
4	FB	Feedback input pin. This pin is connected to the converter output. It is used to set the output of the converter to regulate to the desired value via an internal resistive divider. For an adjustable output, an external resistive divider is connected to this pin on the 1V model.
5	SGND	Signal ground. Connect the return of all small signal components to this pin. (See board layout rules.)
6	$\overline{LL}$	Mode selector switch. When pulled low, the device enters light load mode.
7	EN	Enable input pin. A logic high enables the converter; a logic low forces the AAT1156 into shutdown mode, reducing the supply current to less than 1µA. The pin should not be left floating.
8, 16	NC	Not internally connected.
9	VCC	Bias supply. Supplies power for the internal circuitry. Connect to input power via low pass filter with decoupling to SGND.
10, 11, 12	VP	Input supply voltage for the converter power stage. Must be closely decoupled to PGND.
13, 14, 15	LX	Connect inductor to these pins. Switching node internally connected to the drain of both high- and low-side MOSFETs.
EP		Exposed paddle (bottom); connect to PGND directly beneath package.

Pin Configuration

QFN33-16
(Top View)



Absolute Maximum Ratings[1]

Symbol	Description	Value	Units
V_{CC}, V	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 (QFN33-16)[3]	50	°C/W
P_D	Maximum Power Dissipation (QFN33-16)[4] (T_A = 25°C)	2.0	W

Recommended Operating Conditions

Symbol	Description	Value	Units
T	Ambient Temperature Range	-40 to 85	°C

1. Stresses above those listed in Absolute Maximum Ratings may cause 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 100pF capacitor discharged through a 1.5kΩ resistor into each pin.
3. Mounted on a demo board (FR4, in still air).
4. Derate 20mW/°C above 25°C.

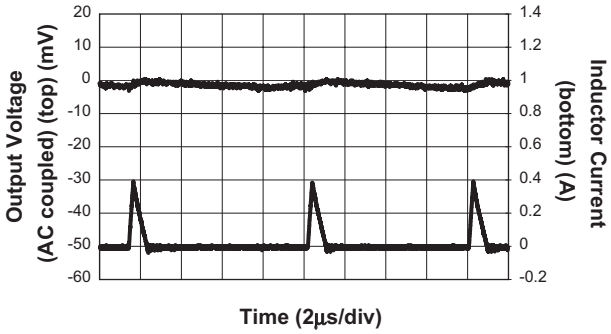
Electrical Characteristics

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.

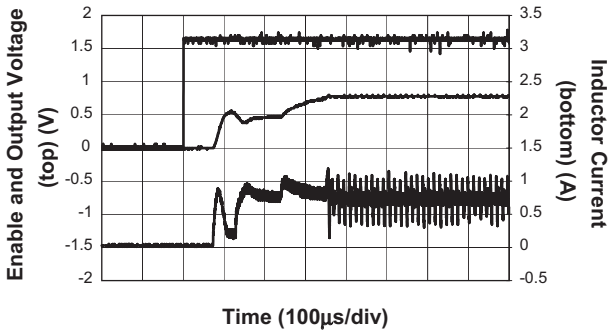
Symbol	Description	Conditions	Min	Typ	Max	Units
V_{IN}	Input Voltage Range		2.7		5.5	V
V_{OUT}	Output Voltage Tolerance	V_{IN} = V_{OUT} + 0.2 to 5.5V, I_{OUT} = 0 to 700mA	-3		3	%
V_{IL}	Input Low Voltage				0.6	V
V_{IH}	Input High Voltage		1.4			V
V_{UVLO}	Under-Voltage Lockout	V_{IN} Rising, V_{EN} = V_{CC}			2.5	V
		V_{IN} Falling, V_{EN} = V_{CC}	1.2			
$V_{UVLO(HYS)}$	Under-Voltage Lockout Hysteresis			250		mV
I_{IL}	Input Low Current	V_{IN} = V_{FB} = 5.5V			1.0	µA
I_{IH}	Input High Current	V_{IN} = V_{FB} = 0V			1.0	µA
I_Q	Quiescent Supply Current	No Load, $\overline{LL}$ = 0V; V_{FB} = 0V, V_{IN} = 4.2V, T_A = 25°C		220	350	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
$\Delta V_{OUT}(V_{OUT}*\Delta V_{IN})$	Load Regulation	V_{IN} = 4.2V, I_{LOAD} = 0 to 700mA		±0.9		%
DV_{OUT}/V_{OUT}	Line Regulation	V_{IN} = 2.7 to 5.5V		±0.1		%/V
F_{OSC}	Oscillator Frequency	T_A = 25°C	750	1000	1350	kHz
T_{SD}	Over-Temperature Shutdown Threshold			140		°C
T_{HYS}	Over-Temperature Shutdown Hysteresis			15		°C

Typical Characteristics

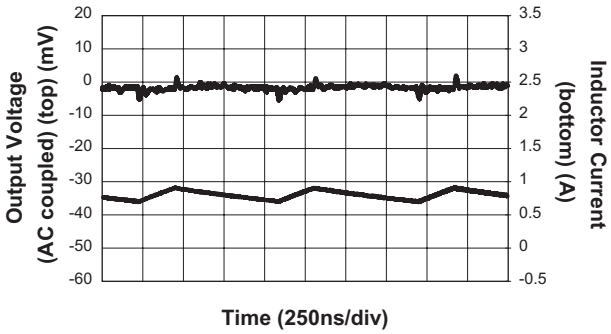
Output Ripple
(0.8V; 10mA; V_{IN} = 3.6V)



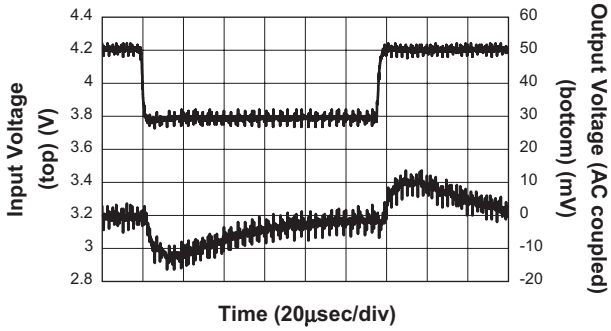
Soft Start
(0.8V; 700mA; V_{IN} = 3.6V)



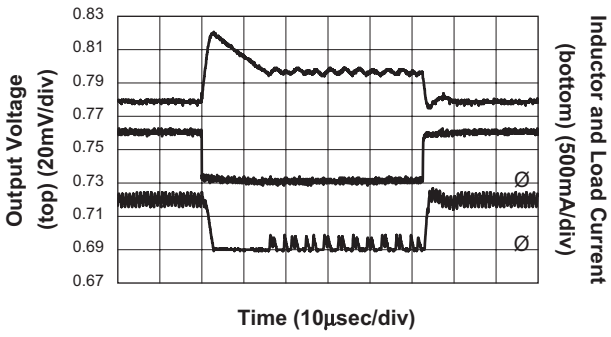
Output Ripple
(0.8V; 700mA; V_{IN} = 3.6V)



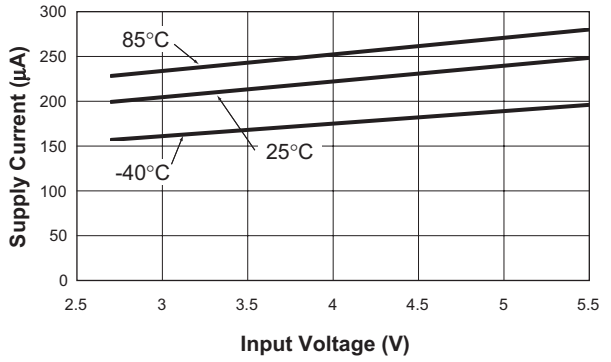
Line Transient
(I_{OUT} = 500mA; V_O = 0.8V)



Load Transient Response
(50mA-680mA; V_{IN} = 3.6V; V_{OUT} = 0.8V)

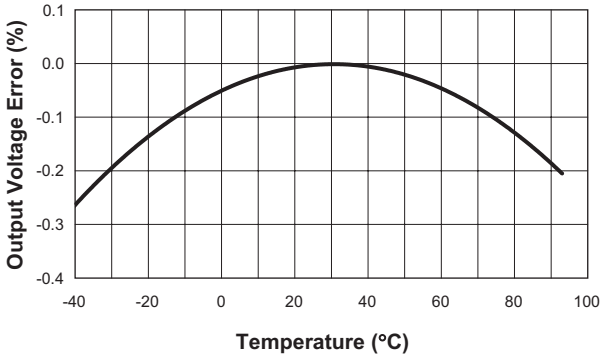


No Load Supply Current vs. Input Voltage

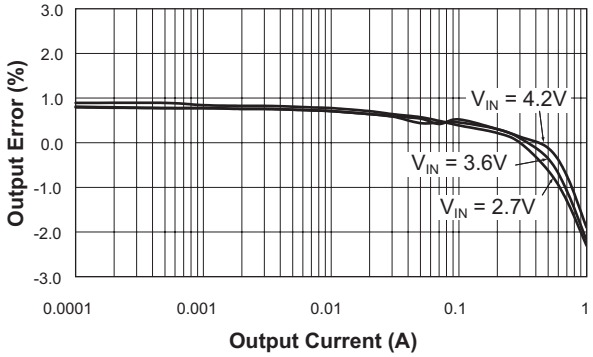


Typical Characteristics

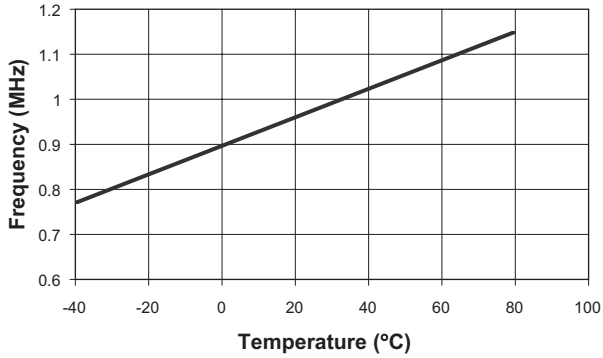
Output Voltage vs. Temperature
(V_{IN} = 4.2V; V_{OUT} = 0.8V; 400mA V_{OUT})



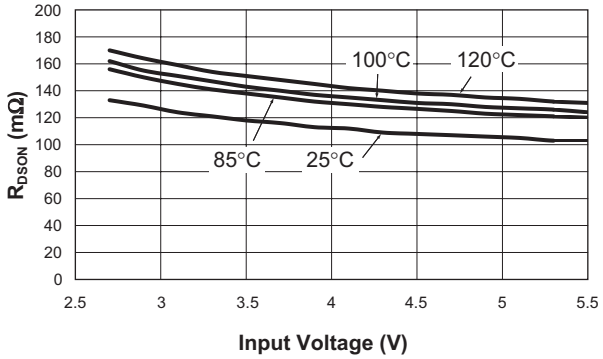
DC Regulation
(V_{OUT} = 0.6V)



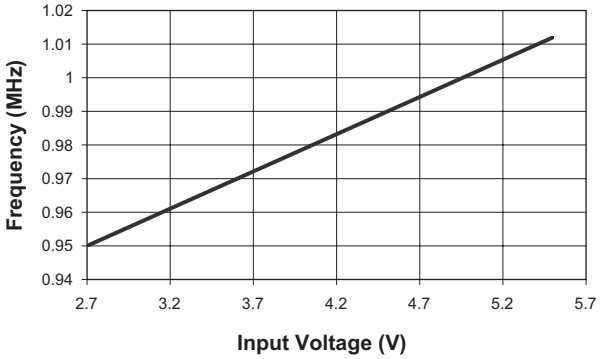
Frequency vs. Temperature
(V_{IN} = 3.6V)



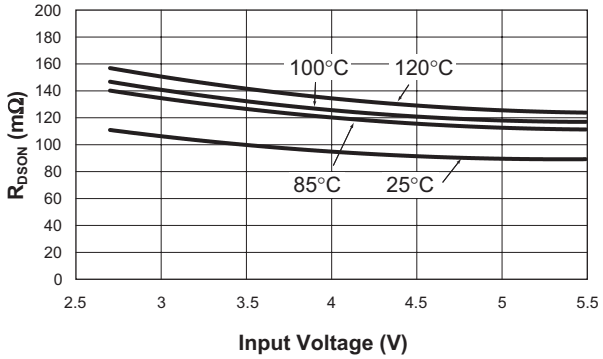
P-Channel R_{DSON} vs. Input Voltage



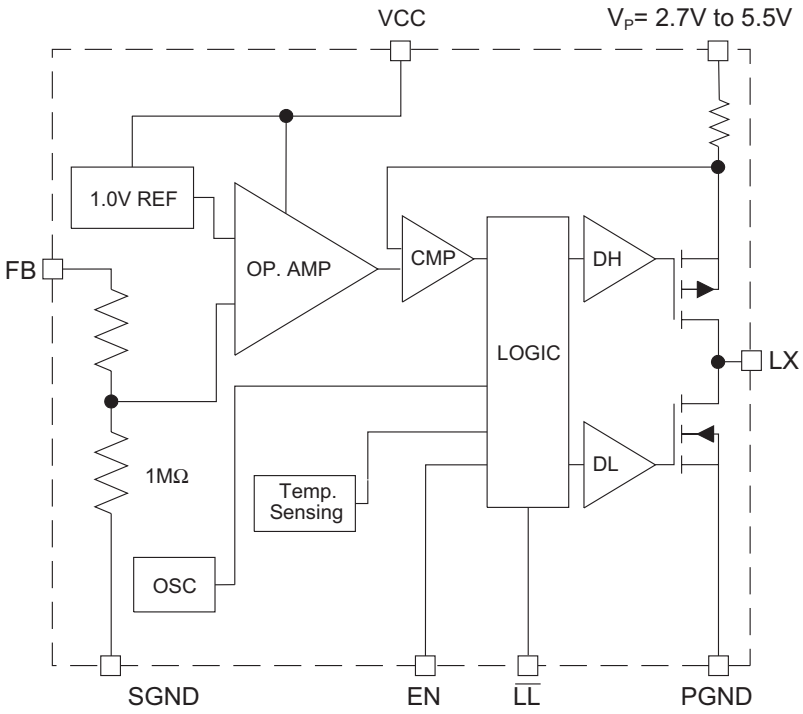
Frequency vs. Input Voltage



N-Channel R_{DSON} vs. Input Voltage



Functional Block Diagram



Operation

Control Loop

The AAT1156 is a peak current mode step-down converter. The inner, wide bandwidth loop controls the inductor peak current. The 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 for duty cycles greater than 50%. 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 external voltage feedback resistive divider divides the output voltage to the error amplifier reference voltage of 0.6V. The voltage error amplifier DC gain is limited. This eliminates the need for external compensation components, while still providing sufficient DC loop gain for good load regulation. The voltage loop crossover frequency and phase margin are set by the output capacitor.

Soft Start/Enable

Soft start increases the inductor current limit point in discrete steps once the input voltage or enable input is applied. It limits the current surge seen at the input and eliminates output voltage overshoot. When pulled low, the enable input forces the AAT1156 into a non-switching shutdown 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 C2 (shown in the schematic in Figure 1) filters the input noise associated with the power switching.

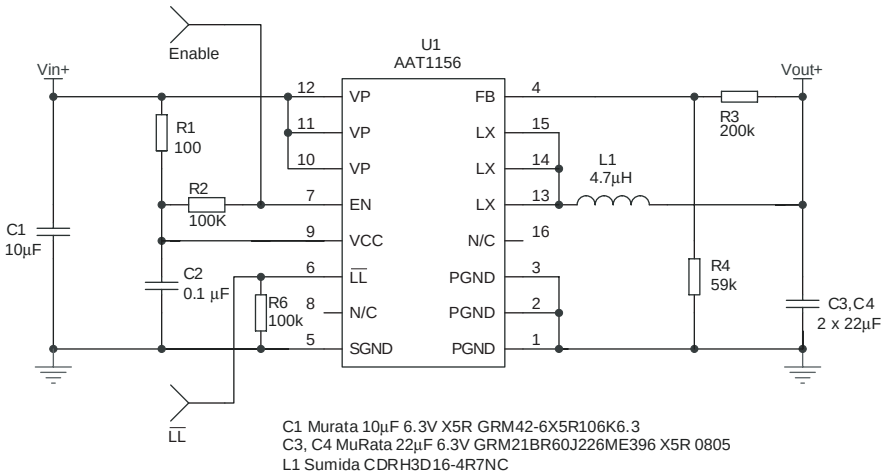


Figure 1: AAT1156 Evaluation Board Schematic—Lithium-Ion to 2.5V Converter.

Current Limit and Over-Temperature Protection

For overload conditions, the peak input current is limited. 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.

Inductor

The output inductor is selected to limit the ripple current to a 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. Some inductors may meet the 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 0.7A, 1.5V output with the ripple set to 40% at a maximum input voltage of 4.2V, the maximum peak-to-peak ripple current is 280mA. The inductance value required is 3.44µH.

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

$$L = \frac{1.5V}{0.7A \cdot 0.4 \cdot 1MHz} \cdot \left(1 - \frac{1.5V}{4.2V}\right)$$

$$L = 3.44\mu H$$

The factor "k" is the fraction of full load selected for the ripple current at the maximum input voltage. For ripple current at 40% of the full load current, the peak current will be 120% of full load. Selecting a standard value of 3.3µH gives 42% ripple current. A 3.3µH inductor selected from the Sumida CDRH3D16 series has a 63mΩ DCR and a 1.1A DC current rating. At full load, the inductor DC loss is 31mW which amounts to less than 3% loss in efficiency for a 0.7A, 1.5V output.

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 AAT1156. 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 AAT1156. 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. Values range from 1µF to 10µF. The input capacitor RMS current varies with the input voltage and 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 is shown in the reference design layout in Figure 2.

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, 0.7A design using the 3.3µH inductor, two 22µF capacitors provide a stable output. In addition to assisting in 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 an X7R or X5R ceramic capacitor, the ESR is so low that 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 well beyond that actually seen in this application.

Layout

Figures 2 and 3 display the suggested PCB layout for the AAT1156. The following guidelines should be used to help ensure a proper layout.

1. The input capacitor (C1) should connect as closely as possible to V_P (Pins 10, 11, and 12) and PGND (Pins 1, 2, and 3).
2. C3, C4, and L1 should be connected as closely as possible. The connection from L1 to the LX node should be as short as possible.
3. The feedback trace (Pin 4) should be separate from any power trace and connect as closely as possible to the load point. Sensing along a high-current load trace will degrade DC load regulation.
4. The resistance of the trace from the load return to the PGND (Pins 1, 2, and 3) should be kept to a minimum. This will help to minimize any error in DC regulation due to differences in the potential of the internal signal ground and the power ground.
5. Low pass filter R1 and C2 provide a cleaner bias source for the AAT1156 active circuitry. C2 should be placed as closely as possible to SGND (Pin 5) and V_{CC} (Pin 9).

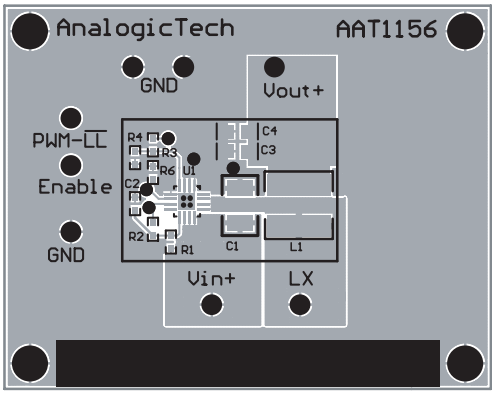


Figure 2: QFN Evaluation Board Top Side.

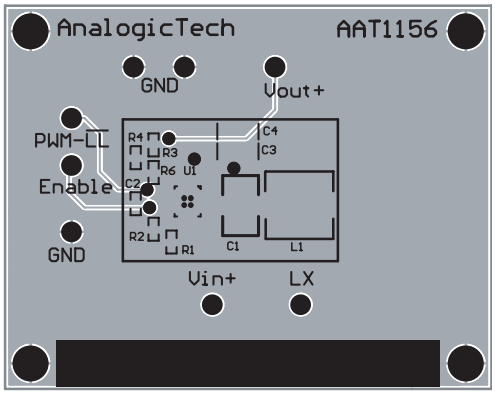


Figure 3: QFN Evaluation Board Bottom Side.

Thermal Calculations

There are three types of losses associated with the AAT1156: MOSFET switching losses, conduction losses, and quiescent current losses. The conduction losses are due to the $R_{DS(ON)}$ characteristics of the internal P- and N-channel MOSFET power devices. At full load, assuming continuous conduction mode (CCM), a simplified form of the total losses is given by:

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

where I_Q is the AAT1156 quiescent current.

Once the total losses have been determined, the junction temperature can be derived from the θ_{JA} for the QFN33-16 package.

$$T_J = P \cdot \Theta_{JA} + T_{AMB}$$

Adjustable Output

Resistors R3 and R4 of Figure 1 force the output to regulate higher than 0.6V. The optimum value for R4 is 59kΩ. Values higher than this may cause problems with stability, while lower values can degrade light load efficiency. For a 2.5V output with R4 set to 59kΩ, R3 is 187kΩ.

$$R3 = \left(\frac{V_O}{V_{REF}} - 1\right) \cdot R4 = \left(\frac{2.5V}{0.6V} - 1\right) \cdot 59k\Omega = 187k\Omega$$

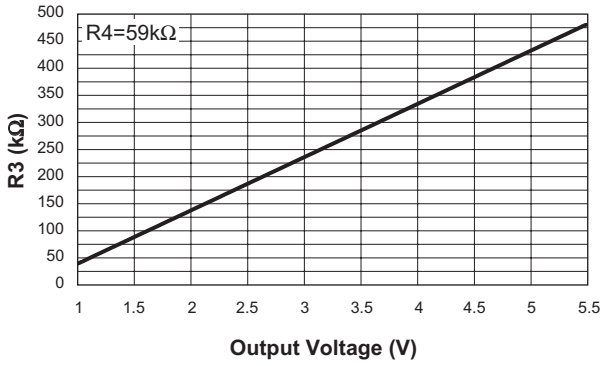


Figure 4: R3 vs. V_{OUT} for Adjustable Output Using the AAT1156.

Design Example

Specifications

I_{OUT} 0.7A

I_{RIPPLE} 40% of Full Load at Max V_{IN}

V_{OUT} 2.5V

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

F_S 1MHz

T_{AMB} 85°C

Maximum Input Capacitor Ripple:

$$I_{RMS} = I_O \cdot \sqrt{\frac{V_O}{V_{IN}} \cdot \left(1 - \frac{V_O}{V_{IN}}\right)} = 0.34\text{Arms},\ V_{IN} = 2 \times V_O$$

$$P = esr \cdot I_{RMS}^2 = 5m\Omega \cdot 0.34^2\ A = 0.6mW$$

Inductor Selection:

$$L = \frac{V_{OUT}}{I_O \cdot k \cdot F} \cdot \left(1 - \frac{V_{OUT}}{V_{IN}}\right) = \frac{2.5V}{0.7A \cdot 0.3 \cdot 1MHz} \cdot \left(1 - \frac{2.5V}{4.2V}\right) = 4.82\mu H$$

Select Sumida inductor CDRH3D16 or CDRH4D28 4.7µH.

$$\Delta I = \frac{V_O}{L \cdot F} \cdot \left(1 - \frac{V_O}{V_{IN}}\right) = \frac{2.5V}{4.7\mu H \cdot 1MHz} \cdot \left(1 - \frac{2.5V}{4.2V}\right) = 220mA$$

$$I_{PK} = I_{OUT} + \frac{\Delta I}{2} = 0.7A + 0.11A = 0.81A$$

$$P = I_O^2 \cdot DCR = (0.7A)^2 \cdot 80m\Omega = 40mW$$

Output Capacitor Ripple Current:

$$I_{RMS} = \frac{1}{2\cdot\sqrt{3}} \cdot \frac{V_{OUT} \cdot (V_{IN} - V_{OUT})}{L \cdot F \cdot V_{IN}} = \frac{1}{2\cdot\sqrt{3}} \cdot \frac{2.5V \cdot (4.2V - 2.5V)}{4.7\mu H \cdot 1MHz \cdot 4.2V} = 62mArms$$

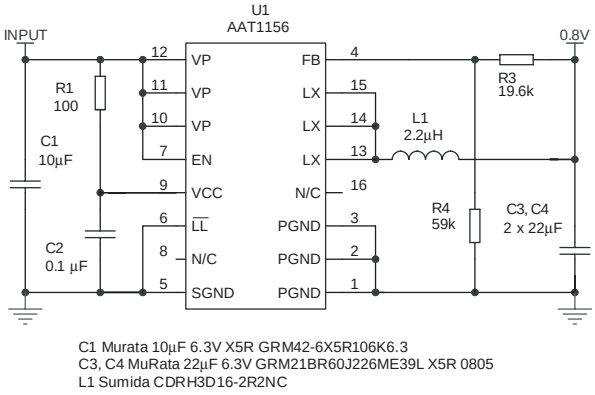
$$Pesr = esr \cdot I_{RMS}^2 = 5m\Omega \cdot (62\ mA)^2 = 19\mu W$$

AAT1156 Dissipation:

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

$$= \frac{(0.7A)^2 \cdot (0.17\Omega \cdot 2.5V + 0.16\Omega \cdot (4.2V - 1.5V))}{4.2V} + (20nsec \cdot 1MHz \cdot 0.7A + 300\mu A) \cdot 4.2V = 0.141W$$

$$T_{J(MAX)} = T_{AMB} + \Theta_{JA} \cdot P_{LOSS} = 85°C + 50°C/W \cdot 0.141W = 92°C$$



C1 Murata 10µF 6.3V X5R GRM42-6X5R106K6.3
C3, C4 MuRata 22µF 6.3V GRM21BR60J226ME39L X5R 0805
L1 Sumida CDRH3D16-2R2NC

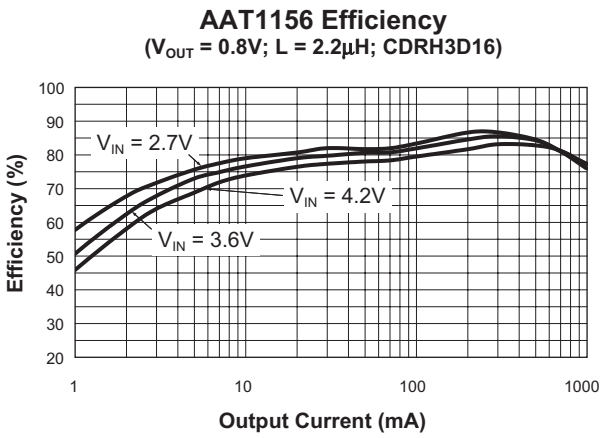


Figure 5: 0.8V Solution.

Surface Mount Inductors

Manufacturer	Part Number	Value	Max DC Current	DCR	Size (mm) L x W x H	Type
TaiyoYuden	NPO5DB4R7M	4.7µH	1.4A	0.038	5.9x6.1x2.8	Shielded
Toko	A914BYW-3R5M-D52LC	3.5µH	1.34A	0.073	5.0x5.0x2.0	Shielded
Sumida	CDRH4D28-4R7	4.7µH	1.32A	0.072	4.7x4.7x3.0	Shielded
Sumida	CDRH3D16-2R2	2.2µH	1.2A	0.050	3.8x3.8x1.8	Shielded
Sumida	CDRH3D16-3R3	3.3µH	1.1A	0.063	3.8x3.8x1.8	Shielded
Sumida	CDRH3D16-4R7	4.7µH	0.9	0.080	3.8x3.8x1.8	Shielded
Sumida	CDRH5D28-4R2	4.2µH	2.2A	0.031	5.7x5.7x3.0	Shielded
Sumida	CDRH5D18-4R1	4.1µH	1.95A	0.057	5.7x5.7x2.0	Sielded
MuRata	LQH55DN4R7M03	4.7µH	2.7A	0.041	5.0x5.0x4.7	Non-Shielded
MuRata	LQH66SN4R7M03	4.7µH	2.2A	0.025	6.3x6.3x4.7	Shielded

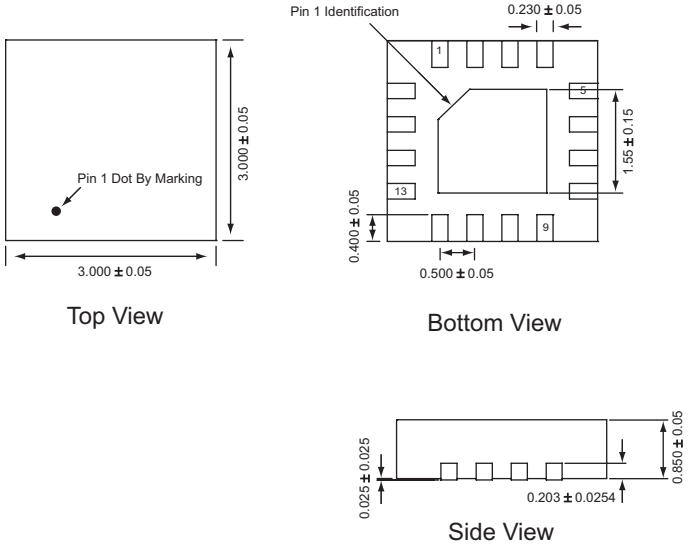
Surface Mount Capacitors

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

Ordering Information

Output Voltage	Package	Marking[1]	Part Number (Tape and Reel)[2]
0.6V (Adj $V_{OUT} \geq 0.8V$)	QFN33-16	LUXYY	**AAT1156IVN-T1**

Package Information



Top View

Bottom View

Side View

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

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