# External NMOS Step-Down PWM Controller

## FEATURES

- N-Channel MOSFET Drive
- Operating Input Voltage from 4.5V to 24V
- Wide Ouput Range : 0.8V to 20V
- ±1.5% 0.8V Reference
- Low Dropout Operation : 95% Duty Cycle
- 500KHz Fixed Constant Frequency
- Low Standby Current, $I_Q$ Typically 720μA
- Logic-Control Micropower Shutdown
- Output Overvoltage Protection
- Internal Diode for Bootstrapped Gate Drive
- Current Mode Operation for Excellent Line and Load Transient Response
- Available in an 8-Lead SO and MSOP Package

## APPLICATIONS

- LCD Monitor
- Palmtop Computers, PDAs
- Wireless Modems
- On-Card Switching Regulators
- DC Power Distribution Systems

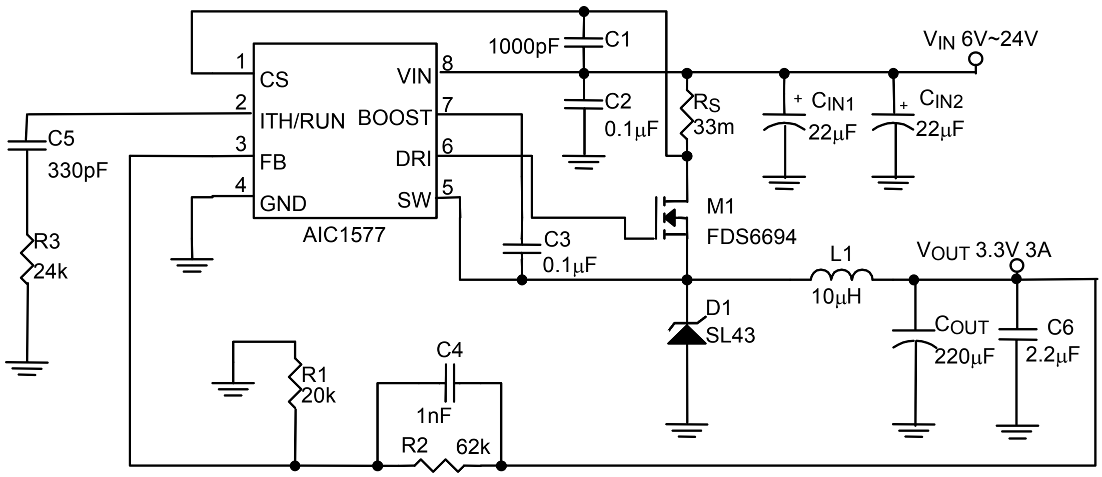
## DESCRIPTION

The AIC1577 is a current mode switching regulator controller that drives external N-channel power MOSFET using a fixed frequency architecure. It uses external divider to adjust output voltage from 0.8V to 20V with excellent line and load regulation. A maximum high duty cycle limit of 95% provides low dropout operation which extends operating time in battery-operated systems.

Switching frequency up to 500KHz are achievable thus allowing smaller sized filter components. The operating current level is user-programmable via an external current sense resistor. It also provide output overvoltage protection under fault conditions.

A multifunction pin ($I_{TH}$/RUN) allows external compensation for optimum load step response plus shutdown. Soft start can also be implemented with this pin to properly sequence supplies. Package available are in SOP8 and MSOP8 for SMD.

## ■ TYPICAL APPLICATION CIRCUIT

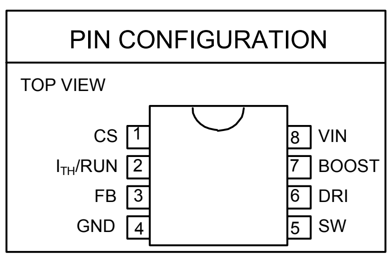



$C_{IN1}$, $C_{IN2}$: HER-MEI 22µF/35V Electrolytic capacitors
M1: FAIRCHILD FDS6694 N-MOSFET
D1: GS SL43
L1: TDK SLF12555T-100M3R4
$C_{OUT}$: HER-MEI 220µF /16V Electrolytic capacitor
C6: TAIYO YUDEN LMK212BJ225KG-T Ceramic capacitor

## ■ ORDERING INFORMATION

AIC1577-XXXX

- PACKING TYPE
  TB: TUBE
  TR: TAPING & REEL
- PACKAGING TYPE
  S: SMALL OUTLINE
  O: MSOP8
- C: Commercial
  P: Lead Free Commercial




Example: AIC1577COTR
→ in MSOP Package & Taping & Reel Packing Type
AIC1577POTR
→ in MSOP Lead Free Package & Taping & Reel Packing Type

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage (VIN) ........ 25V
Drive Supply Voltage (BOOST) ........ 32V
Switch Voltage (SW) ........ 25V
Differential Boost Voltage (BOOST to SW ) ........ 8V
$I_{TH}$/RUN,VFB Voltages ........ 7V
Peak Drive Output Current < 10µS (DRI ) ........ 2A
Operating Temperature Range ........ -40°C ~ 85°C
Junction Temperatrue ........ 125°C
Storage Temperature Range ........ -65°C ~ 150°C
Lead Temperature (Soldering. 10 sec) ........ 260°C
Thernal Resistance ($\theta_{JA}$) (Assume No Ambient Airflow, No Heatsink)
DIP8 ........ 100°C/W
SOP8 ........ 160°C/W
MSOP8 ........ 180°C/W

**Absolute Maximum Ratings are those values beyond which the life of a device may be Impaired.**

## TEST CIRCUIT

Refer to Typical Application Circuit.

## ELECTRICAL CHARACTERISTICS **($T_A$=25°C, $V_{IN}$=15V, unless otherwise noted.) (note1)**

| PARAMETER | TEST CONDITIONS | MIN. | TYP. | MAX. | UNIT |
|---|---|---|---|---|---|
| Input Voltage | | 4.5 | | 24 | V |
| Input Supply Current | Normal Mode (Note 2) | | 720 | 900 | µA |
| | Shutdown Mode, $V_{ITH/RUN}$=0V | | 16 | 20 | µA |
| Feedback Voltage | | 0.788 | 0.8 | 0.812 | V |
| ΔOutput Overvoltage Lockout | $V_{FB}$ connect to Vout, $\Delta V_{OVL}=V_{OVL}-V_{FB}$ | 20 | 55 | 90 | mV |
| Reference Voltage Line Regulation | $V_{IN}$= 4.5V to 20 V | | 0.002 | 0.015 | %/V |
| Output Voltage Load Regulation | $I_{TH}$ Sinking 5µA | | 0.7 | 1.1 | % |
| | $I_{TH}$ Sourcing 5µA | | -0.4 | -0.8 | % |
| Run Threshold | | 0.6 | 0.8 | 0.9 | V |
| Maximum Current Sense Threshold | $V_{FB}$=0.72V | 125 | 150 | 175 | mV |
| Oscillator Frequency | | 450 | 500 | 550 | KHz |

## ■ ELECTRICAL CHARACTERISTICS (Continued)

| PARAMETER | TEST CONDITIONS | MIN. | TYP. | MAX. | UNIT |
|---|---|---|---|---|---|
| DRI Rise Time | $C_{LOAD}$ = 3000pF | | 50 | 75 | nS |
| DRI Fall Time | $C_{LOAD}$ = 3000pF | | 50 | 75 | nS |
| BOOST Voltage | $V_{IN}$=8V, $I_{BOOST}$=5mA, SW=0V | 4.9 | 5.3 | 5.7 | V |
| Maximum Duty Cycle | | 90 | 94 | | % |
| Soft Start Time | | 5 | 7.5 | | mS |
| Run Current Source | $V_{ITH/RUN}$=0V, $V_{FB}$=0V | 1.0 | 2.3 | 4.0 | μA |
| Run Pullup Current | $V_{ITH/RUN}$=1V | 100 | 190 | 250 | μA |

**Note 1:** Specifications are production tested at TA=25°C. Specifications over the -40°C to 85°C operating temperature range are assured by design, characterization and correlation with Statistical Quality Controls (SQC).

**Note 2:** Dynamic supply current is higher due to the gate charge being delivered at the switching frequency.

## ■ TYPICAL PERFORMANCE CHARACTERISTICS

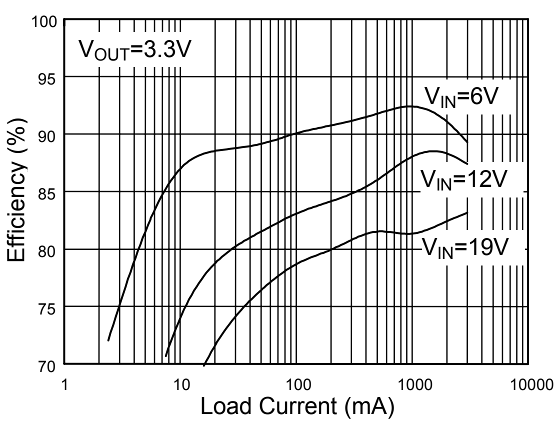


Fig. 1 Efficiency vs Load Current ($V_{OUT}$=3.3V)

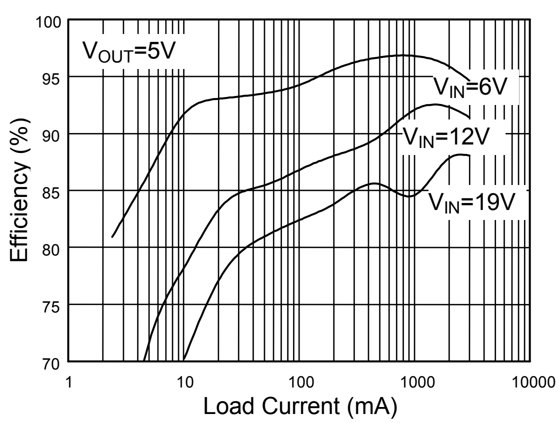


Fig. 2 Efficiency vs Load Current ($V_{OUT}$=5.0V)

## ■ TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

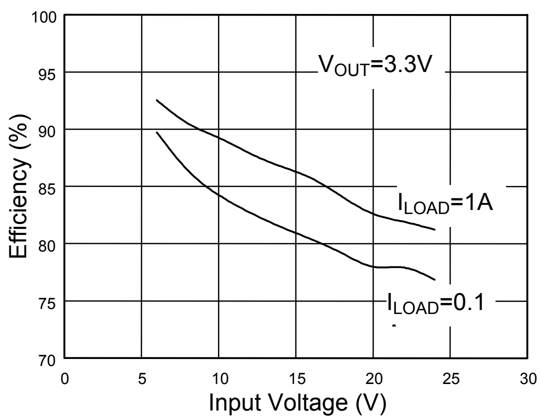


Fig. 3 Efficiency vs Input Voltage

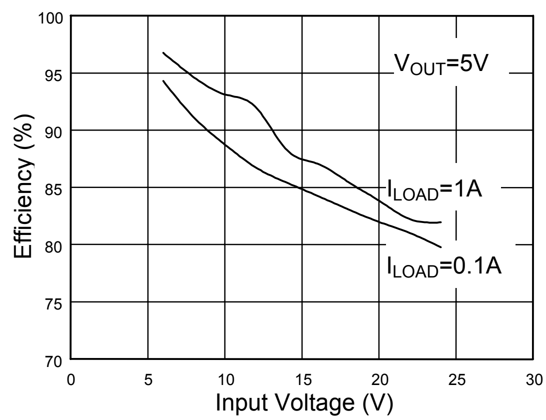


Fig. 4 Efficiency vs Input Voltage

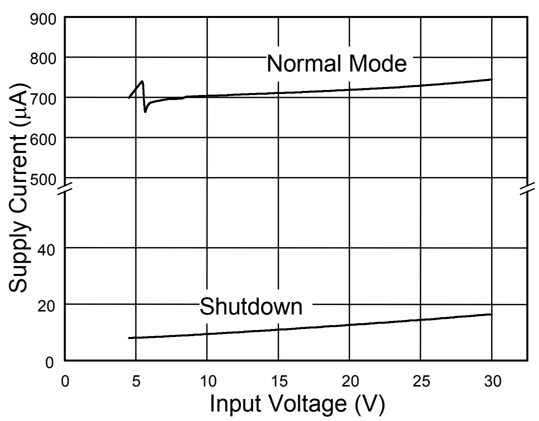


Fig. 5 Supply Current vs Input Voltage

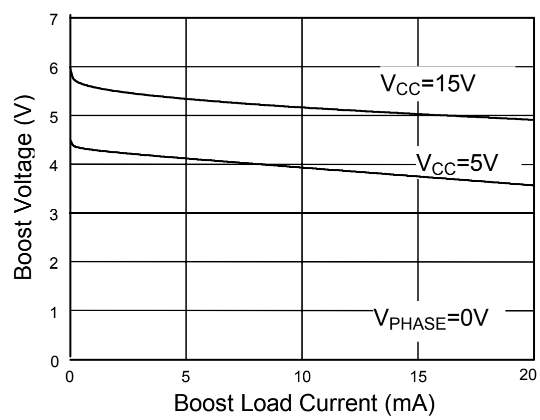


Fig. 6 Boost Load Regulation

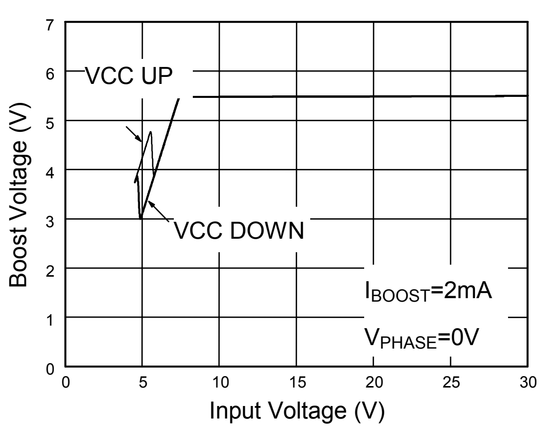


Fig. 7 Boost Line Regulation

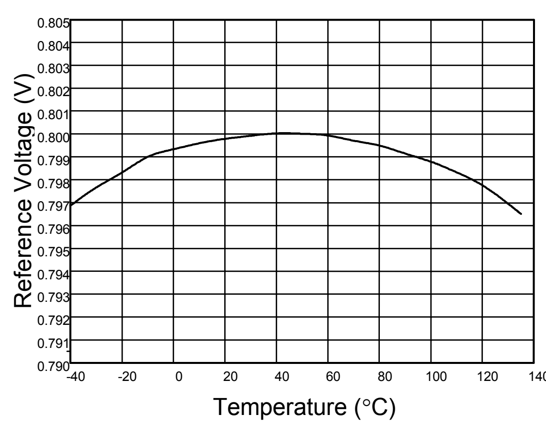


Fig. 8 Reference Voltage vs Temperature

## ■ TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

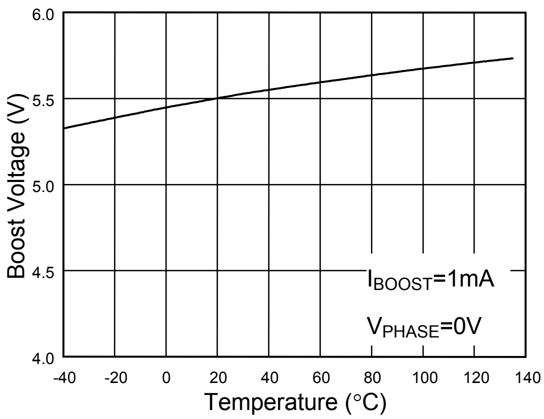



Fig. 9 Boost Voltage vs Temperature

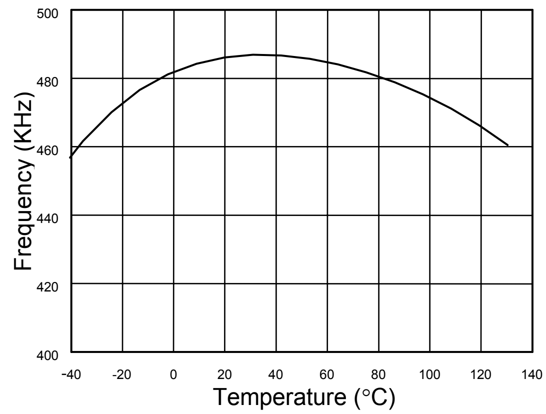



Fig. 10 Operating Frequency vs Temperature

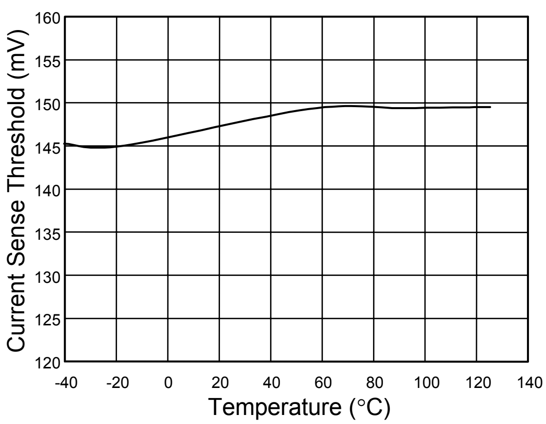
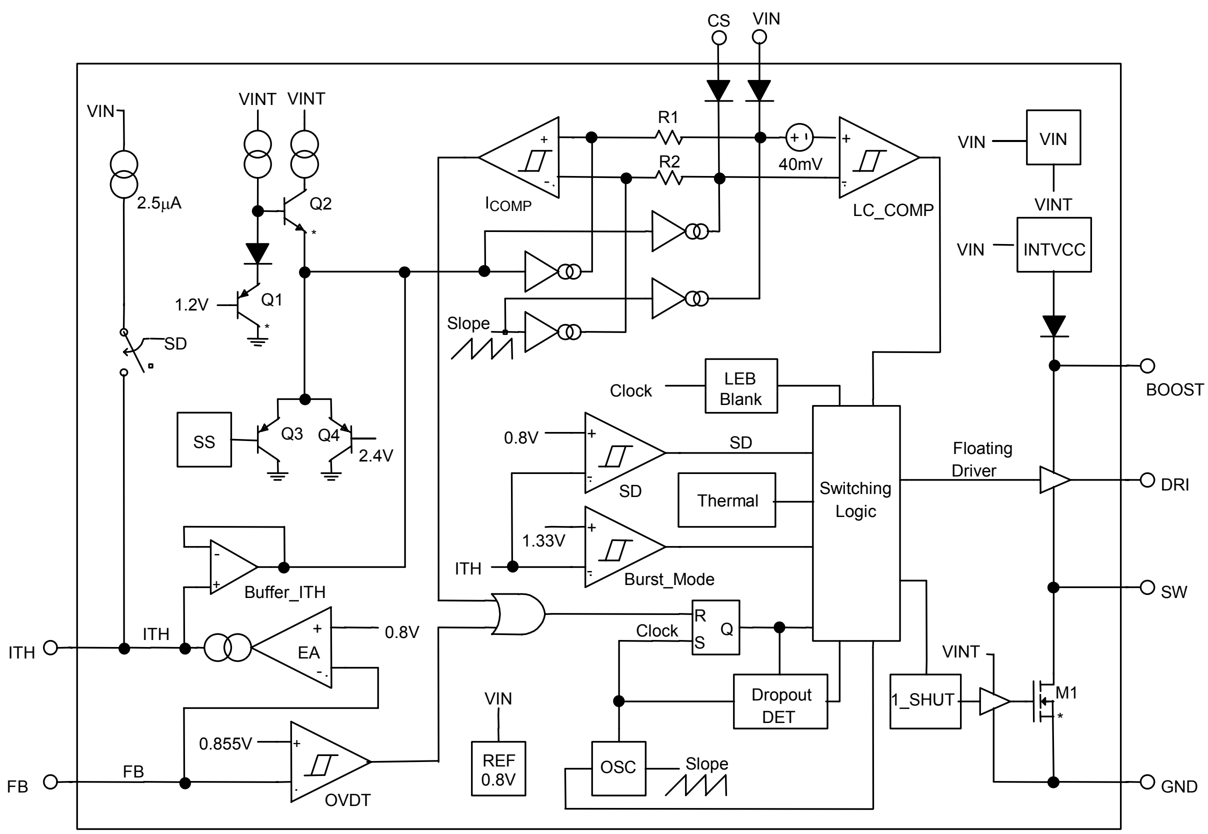



Fig. 11 Maximum Current Sense Threshold vs Temperature

## ■ BLOCK DIAGRAM



## PIN DESCRIPTIONS

PIN 1: CS - Current sense comparator inverting input, not to exceed $V_{IN}$ voltage. Built in offsets between the CS and $V_{IN}$ pins in conjunction with $R_{SENSE}$ set the current trip thresholds.

PIN 2: $I_{TH}$/RUN -Combination of error amplifier compensation point and run control inputs. The current comparator threshold increases with this control voltage. Forcing this pin below 0.8V causes the device to be shutdown.

PIN 3: FB - Feedback error amplifier input, to compare the feedback voltage with the internal reference voltage. Connecting a resistor R2 to converter output node and a resistor R1 to ground yields the output voltage:

$V_{OUT}$=0.8 x (R1+R2)/ R1

PIN4: GND - Singal GND for IC. All voltage levels are measured with respect to this pin.

PIN 5: SW - Switch node connection to inductor. In buck converter applications the voltage swing at this pin is from a schottky diode voltage drop below ground to $V_{IN}$

PIN 6: DRI - External high-side N-MOSFET gate drive pin. Connect DRI to gate of the external high-side N-MOSFET.

PIN 7: BOOST- Supply to high-side floating driver. The bootstrap capacitor C3 is returned to this pin.

PIN 8: VIN - The chip power supply pin. It also provides the gate bias charge for all the MOSFETs controlled by the IC. Recommend supply voltage is 4.5V~24V.

## APPLICATION INFORMATION

**Introduction**

AIC1577 is a current mode switching regulator controller that drives external N-channel power MOSFET with constant frequency architecture. It uses external divider to adjust output voltage with excellent line regulation and load regulation. A maximum high duty cycle limit of 95% provides low dropout operation, which extends operating time in battery-operated system.

Wide input voltage ranges from 4.5V to 24V, and switching frequency (500KHz) allows smaller sized filter components. The operating current level is user-programmable via an external current sense resistor and it automatically enters PFM operation at low output current to boost circuit efficiency.

A multifunction pin ($I_{TH}$/RUN) allows external compensation plus shutdown. A built-in soft start can properly provide sequence supplies. Available packages are in SOP8 and MSOP8 for SMD.

**Principle of Operation**

AIC1577 uses a current mode with a constant frequency architecture. Normally high-side MOSFET turns on each cycle when oscillator sets RS latch and it turns off when internal current comparator resets RS latch. Voltage on $I_{TH}$/RUN pin, which is the output voltage of voltage error amplifier, will control peak inductor current. The output voltage feeds back to $V_{FB}$ pin so that the error amplifier receives a voltage through external resistor divider. When load current increases, it causes a slight decrease in the voltage of $V_{FB}$ pin. Thus the $I_{TH}$/RUN voltage remains increasing until the average inductor current matches new load current. While the high-side MOSFET turns off, the low-side MOSFET is turned on to recharge bootstrap capacitor C3.

Main control loop is shutdown when $I_{TH}$/RUN goes below 0.8V. When $I_{TH}$/RUN pulled up to 0.8V or up by error amplifier, main control loop is enabled.

**Low Current Operation**

During heavy load current operation, AIC1577 operates in PWM mode with a frequency of 500KHz. Decreasing of the current will cause a drop in $I_{TH}$/RUN below 1.33V so that AIC1577 enters PFM mode operation for better efficiency. If the voltage across $R_S$ does not exceed the offset of current comparator within a cycle, then the high-side and internal MOSFETs will disable until $I_{TH}$/RUN goes over 1.33V.

**Component Selection**

AIC1577 can be used in many switching regulator applications, such as step-down, step-up, SEPIC and positive-to-negative converters. Among all, step-down converter is the most common application. External component selection, beginning with selecting $R_S$, depends on load requirement of the application. Once $R_S$ is decided, the choice of inductor, which is followed by selecting power MOSFET and diode, can be easily chosen. Finally, $C_{IN}$ and $C_{OUT}$ can be determined.

**$R_S$ Selection**

The choice of $R_S$ has substantial connection with required output current. The threshold voltage of current comparator decides peak inductor current, which yields a maximum average output current ($I_{MAX}$). And the peak current is less than half of the peak-to-peak ripple current, $\Delta I_L$.

Allowing a margin for variation of AIC1577, external component can be yielded as:

$$R_S = \frac{100mV}{I_{MAX}}$$

**Inductor Selection**

With the operating frequency high to 500KHz, smaller inductor value is favored. In general, operating in high frequency will cause low efficiency because of large MOSFET switching loss. Thus the effect of inductor value on ripple current and low current operation must be considered as well.

The inductor value has a direct influence on ripple current ($\Delta I_L$), which decreases with high inductance and increases with high $V_{IN}$ or $V_{OUT}$:

$$\Delta I_L = \frac{V_{IN} - V_{OUT}}{f \times L}\left(\frac{V_{OUT} + V_D}{V_{IN} + V_D}\right)$$

$V_D$ is the drop voltage of the output Schottky diode.

Accepting a large value of $\Delta I_L$ allows the use of low inductance, but yields high output ripple voltage and large core loss. The inductor value also has an effect on low current operation. Low inductor value causes the PFM operation to begin at high load current. The efficiency of the circuit decreases at the beginning of low current operation. Generally speaking, low inductance in PFM mode will cause the efficiency to decrease.

**Power MOSFET Selection**

For an application of AIC1577, an external N-channel power MOSFET, used as the high-side switch, must be properly selected. To prevent MOSFET from damage during high input voltage operation, attention should be taken to the $BV_{DSS}$ specification for MOSFET.

Other important selection criteria for the power MOSFET include the “ON” resistance $R_{DS(ON)}$, input voltage and maximum output current.

**Output Diode Selection**

In order not to exceed the diode ratings, it is important to specify the diode peak current and average power dissipation.

**$C_{IN}$ and $C_{OUT}$ Selection**

To prevent the high voltage spike resulted from high frequency switching, a low ESR input capacitor for the maximum RMS current must be used. Usually capacitors may be paralleled to meet size or height requirements in the design.

The selection of $C_{OUT}$ depends on the required effective series resistance (ESR). In general once the ESR requirement is met, the capacitance is suitable for filtering. The output ripple voltage ($\Delta V_{OUT}$) is determined by:

$$\Delta V_{OUT} \approx \Delta I_L \left( ESR + \frac{1}{4fC_{OUT}} \right)$$

where f = operating frequency, $C_{OUT}$ = output capacitance and $\Delta I_L$ = ripple current of the inductor. Once the ESR requirement for $C_{OUT}$ has been met, the RMS current rating generally far exceeds the $I_{RIPPLE(P-P)}$ requirement.

**Topside MOSFET Driver Supply (C3)**

External bootstrap capacitor C3 connecting to BOOST pin supplies the gate drive voltage for high-side MOSFET. C3 is charged from $INTV_{CC}$ when SW pin is low. When the high-side MOSFET turns on, the driver places the C3 voltage across the gate to the source of MOSFET. It will enhance the MOSFET and turn on the high-side switch. Then the switch node voltage SW rises to $V_{IN}$ and BOOST pin rises to $V_{IN}$ + $INTV_{CC}$. In general, 0.1µF is acceptable.

**Output Voltage Programming**

The typical AIC1577 application circuit is shown in figure18. A resistive divider, as in the following formula, sets the output voltage.

$$V_{OUT} = 0.8V\left(1 + \frac{R2}{R1}\right)$$

The feedback reference voltage 0.8V allows low output voltages from 0.8V to input voltage. A small capacitor at 1nF in parallel to the upper feedback resistor is required for a stable feedback.

**$I_{TH}$/RUN Function**

The $I_{TH}$/RUN pin, also as a dual-purpose pin, provides loop compensation as well as shutdown function. An internal current source at 2.5µA charges up the external capacitor C5. When the voltage on $I_{TH}$/RUN pin reaches 0.8V, the AIC1577 begins to operate.

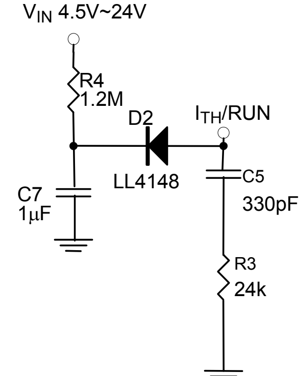



Fig. 12 $I_{TH}$/RUN pin interfacing

**Over Current Protection**

Over current protection occurs when the peak inductor current reaches maximum current sense threshold divided by sense resistor. The maximum current under over current protection can be calculated by the following formula.

$$I_{MAX} = \frac{150mV(\text{Maximum current sense threshold})}{R_S}$$

At the same time, the frequency of oscillator will be reduced to sixteenth of original value, 500kHz. This lower frequency allows the inductor current to safely discharge, thereby preventing current runaway. The frequency of oscillator will automatically return to its designed value when the peak inductor value no longer exceeds over current protection point.

**Over Voltage Protection**

Over voltage protection occurs when the FB pin voltage (the negative input of error amplifier) exceeds 0.855V. The over voltage comparator will force driver to pull low until output over voltage is removed.

**PCB Layout**

Since operating in a high switching frequency, 500KHz, proper PCB layout and component placement may enhance the performance of AIC 1577 application circuit. For a better efficiency, major loop from input terminal to output terminal should be as short as possible. In addition, in the case of a large current loop, the track width of each component in the loop should maintain as wide as possible.

In order to prevent the effect from noise, the GND pin should be placed close to the ground. Also keep the IC's GND pin and the ground leads in the shortest distance. Recommended layout diagrams and component placement are as shown as figures 13 to 16. No sensitive components, which may cause noise interference to the circuit, should be allowed to be close to SW pin.

Furthermore, AIC1577 is a current mode controller. Remaining the sense resistor close to both VIN and CS pins is recommended for better efficiency and output performance. In addition, all filtering and decoupling capacitors, such as C1 and C2, should connect to AIC1577 as close as possible.

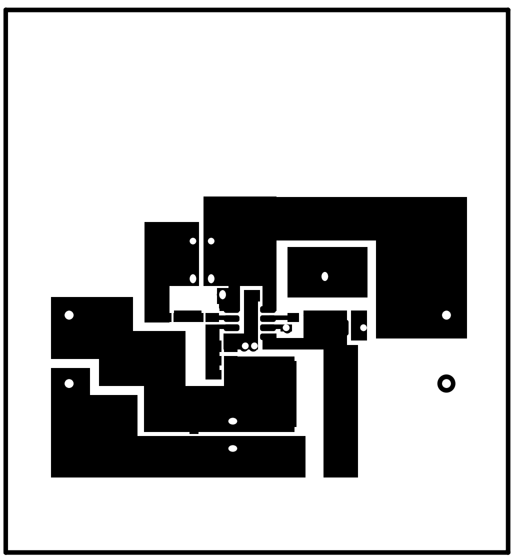


Fig. 13 Top Layer

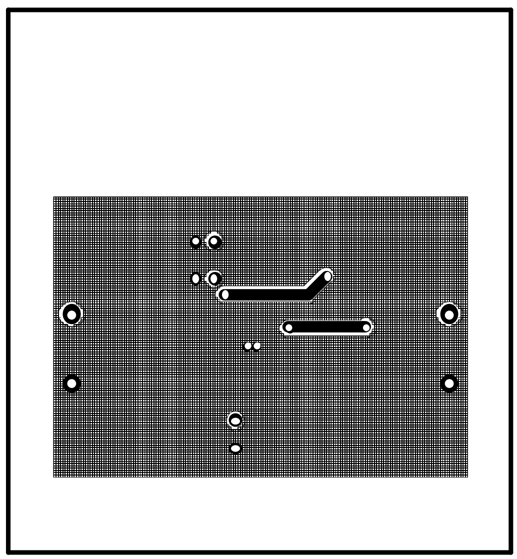


Fig. 14 Bottom Layer

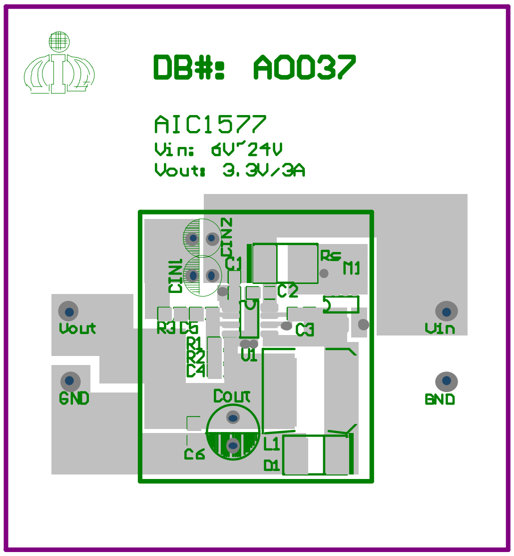



Fig. 15 Placement (Top Overlay)

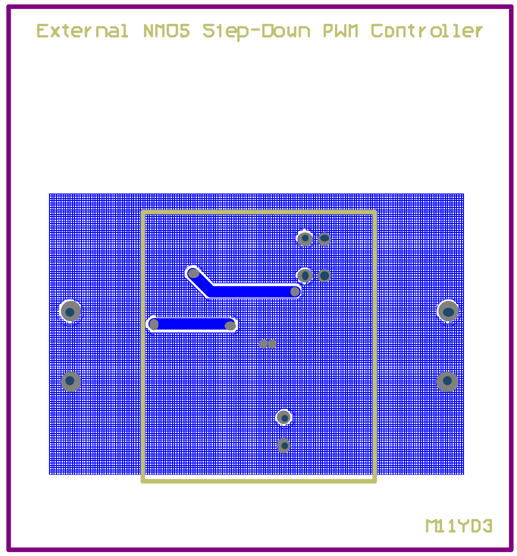



Fig. 16 Placement (Bottom Overlay)

## ■ APPLICATION CIRCUIT

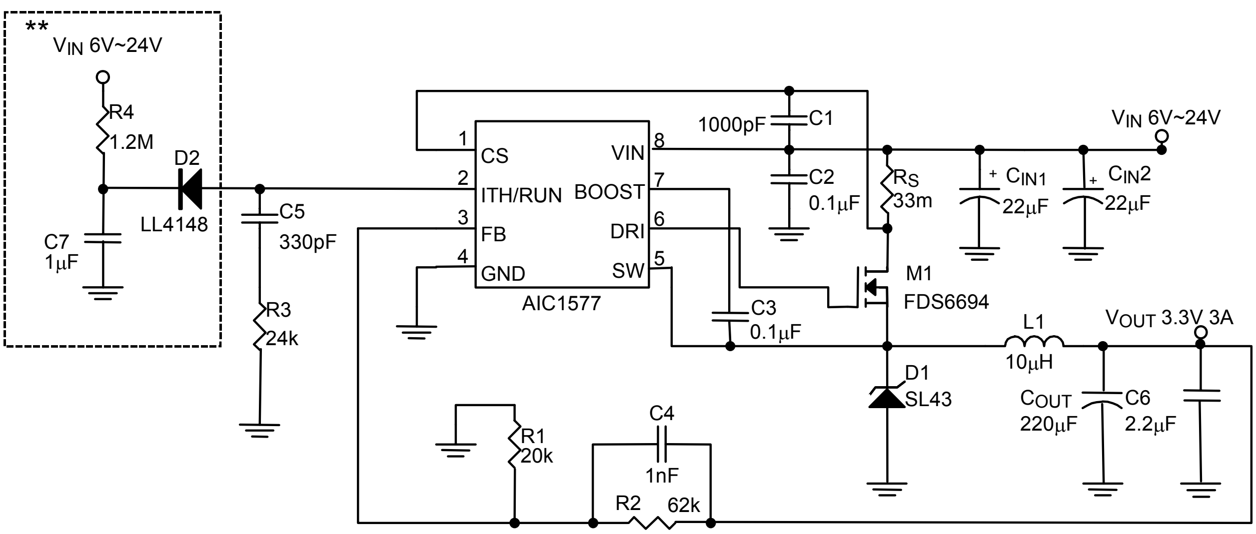



Fig. 17 3.3V Step-Down Converter with External Soft-Start Circuit

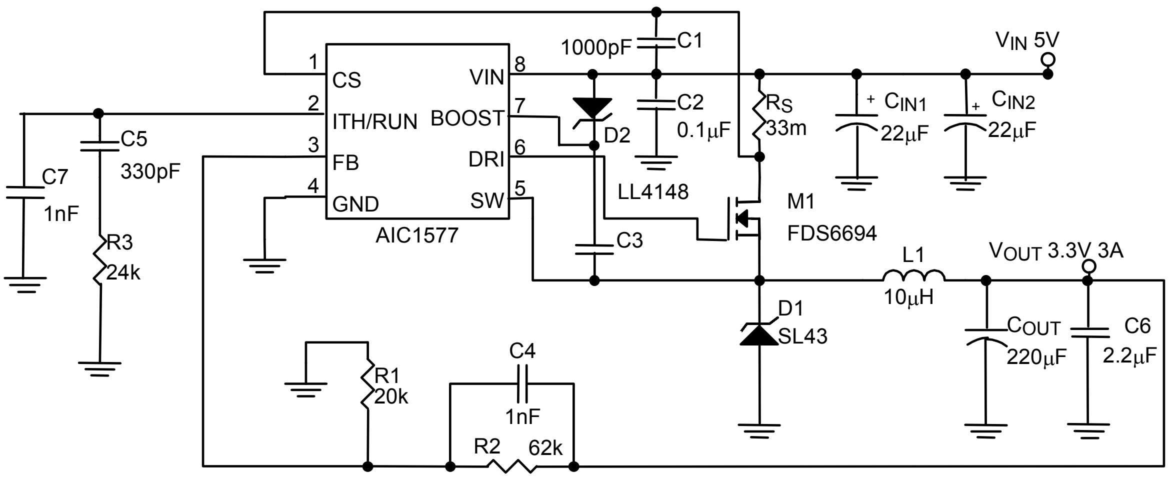
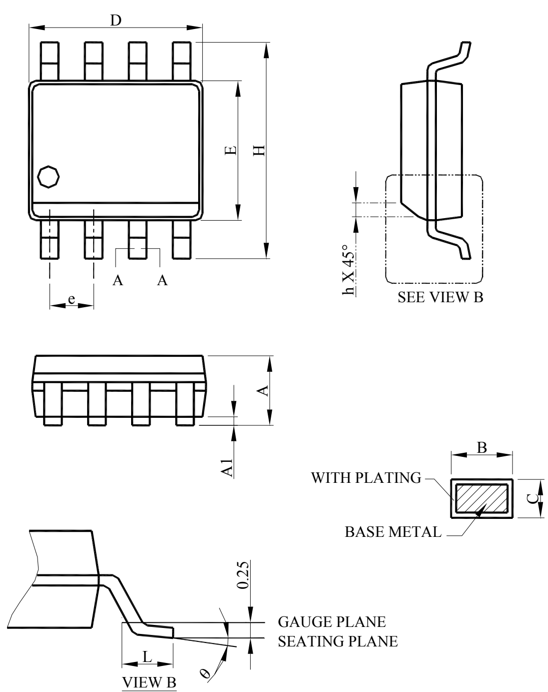



Fig. 18 5V to 3.3V Step-Down Converter

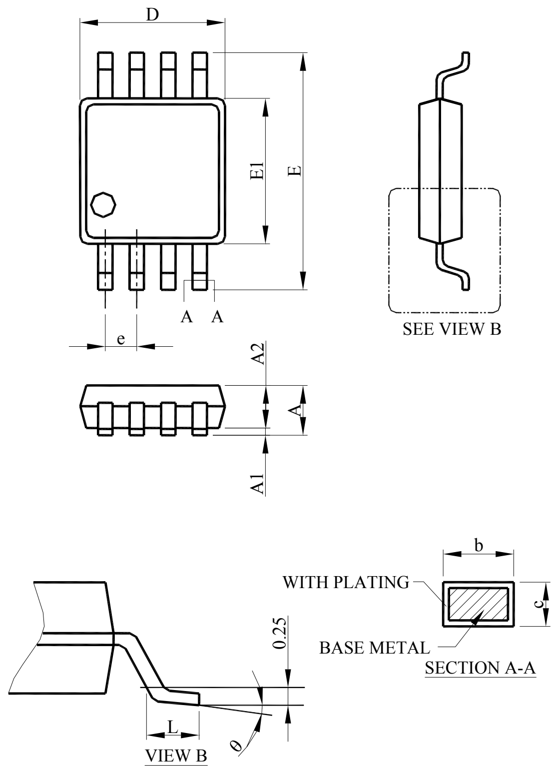
## ■ PHYSICAL DIMENSIONS (unit: mm)

- **8 LEAD PLASTIC SO**




| SYMBOL | SOP-8 | |
|---|---|---|
| | MILLIMETERS | |
| | MIN. | MAX. |
| A | 1.35 | 1.75 |
| A1 | 0.10 | 0.25 |
| B | 0.33 | 0.51 |
| C | 0.19 | 0.25 |
| D | 4.80 | 5.00 |
| E | 3.80 | 4.00 |
| e | 1.27 BSC | |
| H | 5.80 | 6.20 |
| h | 0.25 | 0.50 |
| L | 0.40 | 1.27 |
| θ | 0° | 8° |

- **MSOP 8**




| SYMBOL | MSOP-8 | |
|---|---|---|
| | MILLIMETERS | |
| | MIN. | MAX. |
| A | | 1.10 |
| A1 | 0.05 | 0.15 |
| A2 | 0.75 | 0.95 |
| b | 0.25 | 0.40 |
| c | 0.13 | 0.23 |
| D | 2.90 | 3.10 |
| E | 4.90 BSC | |
| E1 | 2.90 | 3.10 |
| e | 0.65 BSC | |
| L | 0.40 | 0.70 |
| θ | 0° | 6° |

**Note:**

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