FAIRCHILD SEMICONDUCTOR®

November 2007

FAN2106 — TinyBuck™
6A, 24V Input Integrated Synchronous Buck Regulator

Features

- Over 95% efficiency
- Internal power MOSFETs:
  High-side $R_{DS(ON)}$ = 30mΩ
  Low-side $R_{DS(ON)}$ = 14mΩ
- Integrated low-side Schottky diode
- Programmable frequency operation
- Power-good signal
- Wide input range: 3.0V to 24V
- Output voltage range: 0.8V to 90%V_{IN}
- Input under-voltage lockout (UVLO)
- Programmable over-current protection
- Under-voltage, over-voltage, and thermal protection
- Selectable light-load power-saving mode
- 5x6mm, 25-pin, 3-pad MLP

Applications

- Thin and light Notebook PCs
- Graphics cards
- Battery-powered equipment
- Set-top box
- Point-of-load regulation

Description

The FAN2106 TinyBuck™ is an easy-to-use, cost and space-efficient, synchronous buck solution. It enables designers to solve high current requirements in a small area with minimal external components.

External programming of clock frequency, current limit, and loop response allows for optimization and flexibility selecting output filter components and transient response.

The summing current mode modulator uses lossless current sensing for current feedback and over-current, and includes voltage feedforward.

Fairchild's advanced BiCMOS power process, combined with a thermally efficient MLP package, provides low-$R_{DS(ON)}$ internal MOSFETs and the ability to dissipate high power in a small package.

Under-voltage, thermal shutdown, and power-good protect the device from damage during fault conditions.

Related Application Notes

- *AN-6033 — FAN2106 Design Guide*

Ordering Information

Part Number	Operating Temperature Range	Package	Packing Method
FAN2106MPX	-10°C to 85°C	Molded Leadless Package (MLP) 5x6mm	Tape and Reel
FAN2106EMPX	-40°C to 85°C	Molded Leadless Package (MLP) 5x6mm	Tape and Reel

All packages are lead free per JEDEC: J-STD-020B standard.

Typical Application Diagram

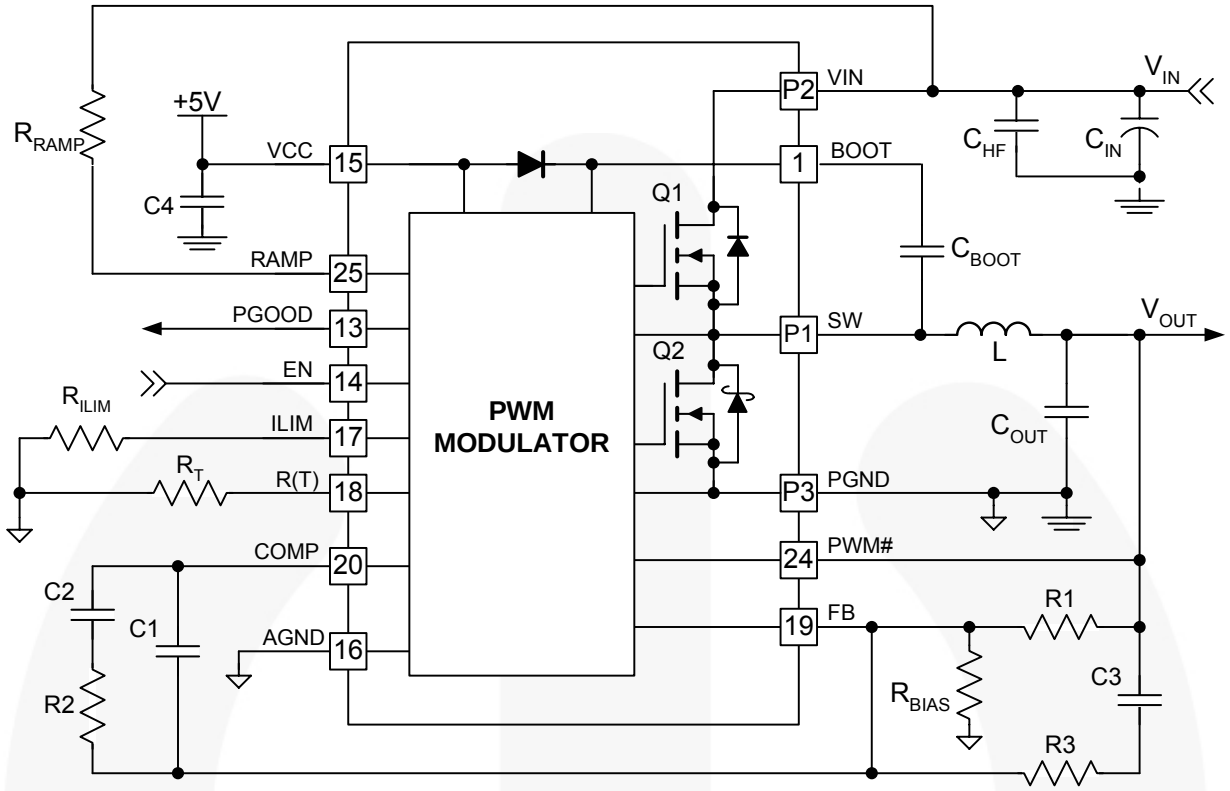

Figure 1. Typical Application

Block Diagram

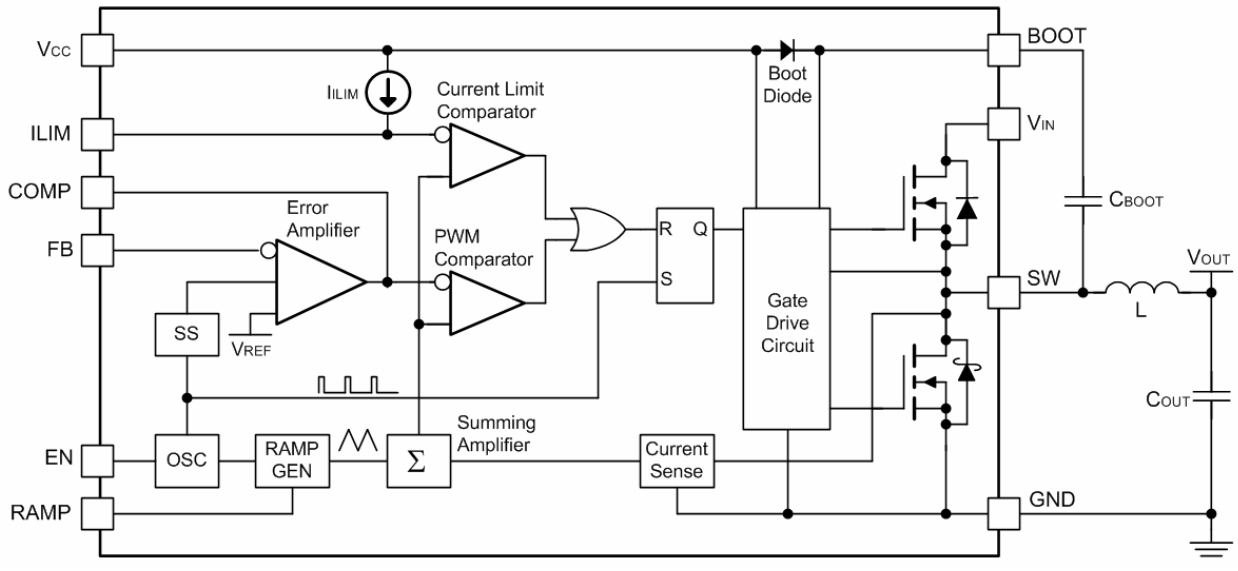

Figure 2. Block Diagram

Pin Configuration

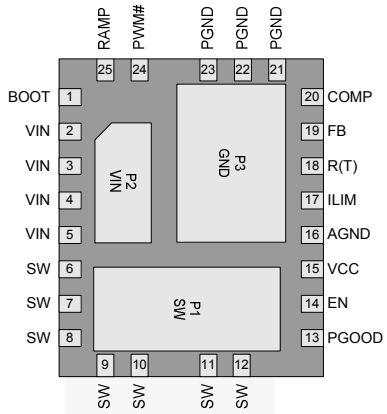

Figure 3. MLP 5x6mm Pin Configuration (PCB Layout View)

Pin Definitions

Pin	Name	Description
P1, 6-12	SW	**Switching Node**.
P2, 2-5	VIN	**Power Input Voltage**. Connect to the main input power source.
P3, 21-23	PGND	**Power Ground**. Power return and Q2 source.
1	BOOT	**High-Side Drive BOOT Voltage**. Connect through capacitor (C_{BOOT}) to SW. The IC includes an internal synchronous bootstrap diode to recharge the capacitor on this pin to V_{CC} when SW is LOW.
13	PGOOD	**Power-Good Flag**. An open-drain output that pulls LOW when FB is outside a ±10% range of the reference. PGOOD does not assert HIGH until the fault latch is enabled.
14	EN	**ENABLE**. Enables operation when pulled to logic HIGH or left open. Toggling EN resets the regulator after a latched fault condition. This input has an internal pull-up when the IC is functioning normally. When a latched fault occurs, EN is discharged by a current sink.
15	VCC	**Input Bias Supply for IC**. The IC's logic and analog circuitry are powered from this pin.
16	AGND	**Analog Ground**. The signal ground for the IC. All internal control voltages are referred to this pin. Tie this pin to the ground island/plane through the lowest impedance connection.
17	ILIM	**Current Limit**. A resistor (R_{ILIM}) from this pin to AGND can be used to program the current-limit trip threshold lower than the default setting.
18	R(T)	**Oscillator Frequency**. A resistor (R_T) from this pin to AGND sets the PWM switching frequency.
19	FB	**Output Voltage Feedback**. Connect through a resistor divider to the output voltage.
20	COMP	**Compensation**. Error amplifier output. Connect the external compensation network between this pin and FB.
24	PWM# / VOUT	**Forced PWM / VOUT**. Connect to VOUT to enable light-load, power-saving mode of operation. Connect to GND or leave open for PWM mode.
25	RAMP	**Ramp Amplitude**. A resistor (R_{RAMP}) connected from this pin to VIN sets the ramp amplitude and provides voltage feedforward functionality.

Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

Parameter	Conditions	Min.	Max.	Unit
VIN to PGND			28	V
VCC to AGND	AGND = PGND		6	V
BOOT to PGND			35	V
BOOT to SW		-0.3	6.0	V
SW to PGND	Continuous	-0.5	24.0	V
	Transient (t < 20nsec, F ≤ 600KHz)	-5	30	V
All other pins		-0.3	V_{CC}+0.3	V

Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended operating conditions are specified to ensure optimal performance to the datasheet specifications. Fairchild does not recommend exceeding them or designing to absolute maximum ratings.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{CC}	Bias Voltage	VCC to AGND	4.5	5.0	5.5	V
V_{IN}	Supply Voltage	VIN to PGND	3		24	V
T_A	Ambient Temperature	FAN2106M	-10		85	°C
		FAN2106EM	-40		85	°C
T_J	Junction Temperature				125	°C

Thermal Information

Symbol	Parameter		Min.	Typ.	Max.	Unit
T_{STG}	Storage Temperature		-65		150	°C
T_L	Lead Soldering Temperature, 10 seconds				300	°C
T_{VP}	Vapor Phase, 60 seconds				215	°C
T_I	Infrared, 15 seconds				220	°C
θ_{JC}	Thermal Resistance: Junction-to-Case	P1 (Q2)		4		°C/W
		P2 (Q1)		7		°C/W
		P3		4		°C/W
$\theta_{J\text{-}PCB}$	Thermal Resistance: Junction-to-Mounting Surface			35(1)		°C/W
P_D	Power Dissipation, T_A = 25°C				2.8(1)	W

Note:

1. Typical thermal resistance when mounted on a four-layer, two-ounce PCB, as shown in Figure 26. Actual results are dependent on mounting method and surface related to the design.

Electrical Specifications

Recommended operating conditions are the result of using the circuit shown in Figure 1 unless otherwise noted.

Parameter	Conditions	Min.	Typ.	Max.	Unit
Power Supplies					
V_{CC} Current	SW = Open, FB = 0.7V, V_{CC} = 5V, F_{SW} = 600KHz		8	12	mA
	Shutdown: EN = 0, V_{CC} = 5V		7	10	µA
	Power Saving Mode, V_{CC} = 5V, F_{MIN}		2.2	4.5	mA
V_{CC} UVLO Threshold	Rising V_{CC}	4.1	4.3	4.5	V
	Hysteresis		300		mV
Power Output Section					
N-Channel (Q1) $R_{DS(ON)}$	V_{CC} = 5V, 25°C		30	35	mΩ
N-Channel (Q2) $R_{DS(ON)}$			14	16	mΩ
Oscillator					
Frequency	R_T = 50KΩ	255	300	345	KHz
	R_T = 24KΩ	540	600	660	KHz
Minimum On-Time[2]			50	65	nsec
Ramp Amplitude, pk–pk	16V_{IN}, 1.8V_{OUT}, R_T = 30KΩ, R_{RAMP} = 200KΩ		0.53		V
Minimum Off-Time[2]			100	150	nsec
Reference					
Reference Voltage (V_{FB})	FAN2106M, 25°C	794	800	806	mV
	FAN2106EM, 25°C	795	800	805	mV
Error Amplifier					
DC Gain[2]	V_{CC} = 5V	80	85		dB
Gain Bandwidth Product[2]		12	15		MHz
Output Voltage (V_{COMP})		0.4		3.2	V
Output Current, Sourcing	V_{CC} = 5V, V_{COMP} = 2.2V	1.5	2.2		mA
Output Current, Sinking	V_{CC} = 5V, V_{COMP} = 1.2V	0.8	1.2		mA
FB Bias Current	V_{FB} = 0.8V, 25°C	-850	-650	-450	nA
Protection and Shutdown					
Current Limit	R_{ILIM} open	6	8	10	A
I_{LIM} Current		-11	-10	-9	µA
Over-Temperature Shutdown	Internal temperature		155		°C
Over-Temperature Hysteresis			30		°C
Over-Voltage Threshold	2 consecutive clock cycles	110	115	120	%V_{OUT}
Under-Voltage Shutdown	16 consecutive clock cycles	68	73	78	%V_{OUT}
Fault Discharge Threshold	Measured at FB pin		250		mV
Fault Discharge Hysteresis	Measured at FB pin (V_{FB} ~500mV)		250		mV

Note:

2. Specifications guaranteed by design and characterization; not production tested.

Electrical Specifications (Continued)

Recommended operating conditions are the result of using the circuit shown in Figure 1 unless otherwise noted.

Parameter	Conditions	Min.	Typ.	Max.	Unit
Soft-Start					
V_{OUT} to Regulation ($T_{0.8}$)	Frequency = 600KHz		5.3		msec
Fault Enable/SSOK ($T_{1.0}$)			6.7		msec
Control Functions					
EN Threshold, Rising			1.35	2.0	V
EN Hysteresis			250		mV
EN Pull-Up Resistance			800		KΩ
EN Discharge Current	Auto-restart mode		1		µA
FB OK Drive Resistance				800	Ω
PGOOD Threshold	FB < V_{REF}	-14	-11	-8	%V_{FB}
	FB > V_{REF}	107	110	113	%V_{FB}
PGOOD Output Low	$I_{OUT} \leq$ 2mA			0.4	V
PGOOD Output High	V_{PGOOD} = 5V			1	µA
PWM# Threshold			0.6	0.8	V
PWM# Input Current	$V_{PWM\#}$ = 0.4V		1.0	1.2	µA

Typical Characteristics

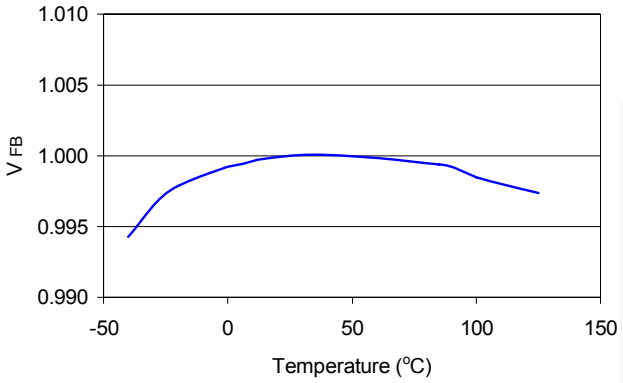

Figure 4. Reference Voltage (V_{FB}) vs. Temperature, Normalized

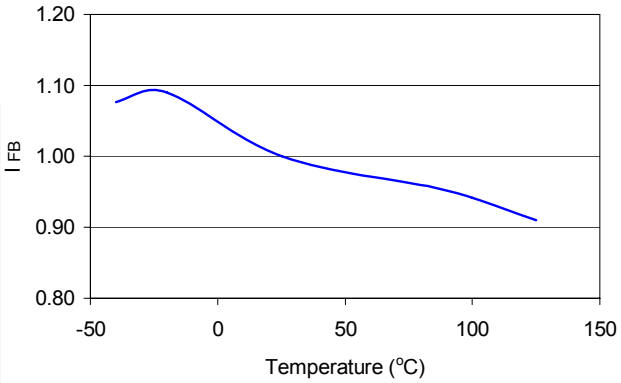

Figure 5. Reference Bias Current (I_{FB}) vs. Temperature, Normalized

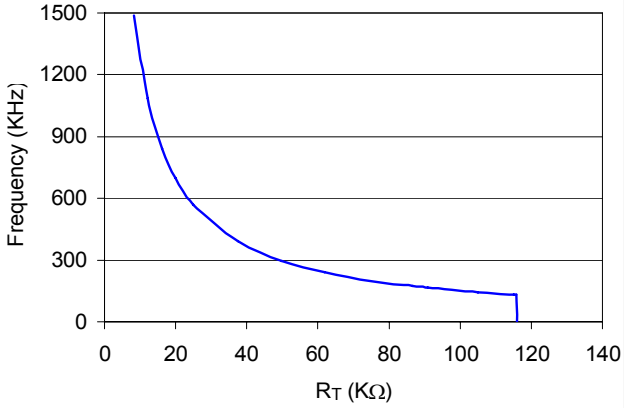

Figure 6. Frequency vs. R_T

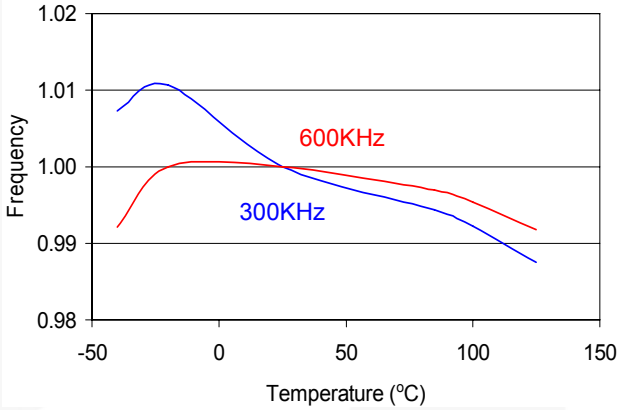

Figure 7. Frequency vs. Temperature, Normalized

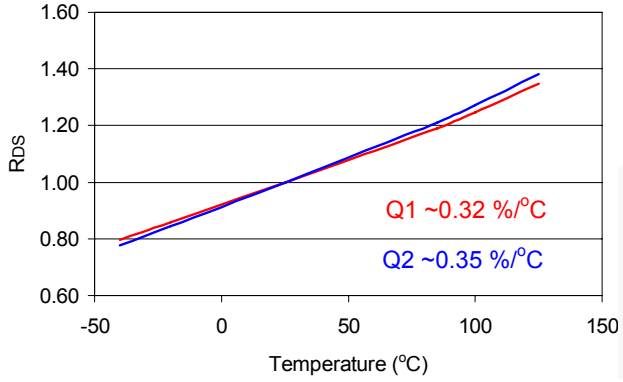

Figure 8. R_{DS} vs. Temperature, Normalized (V_{CC} = V_{GS} = 5V)

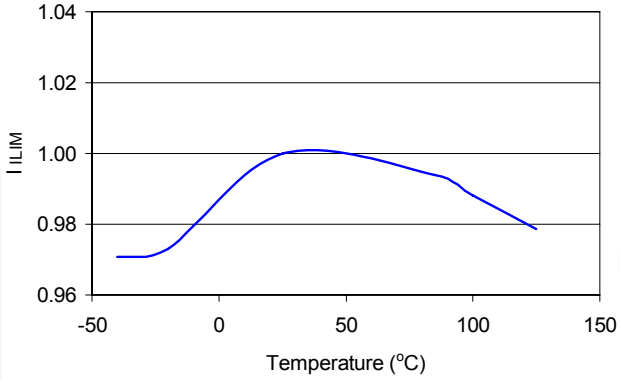

Figure 9. ILIM Current (I_{ILIM}) vs. Temperature, Normalized

Application Circuit

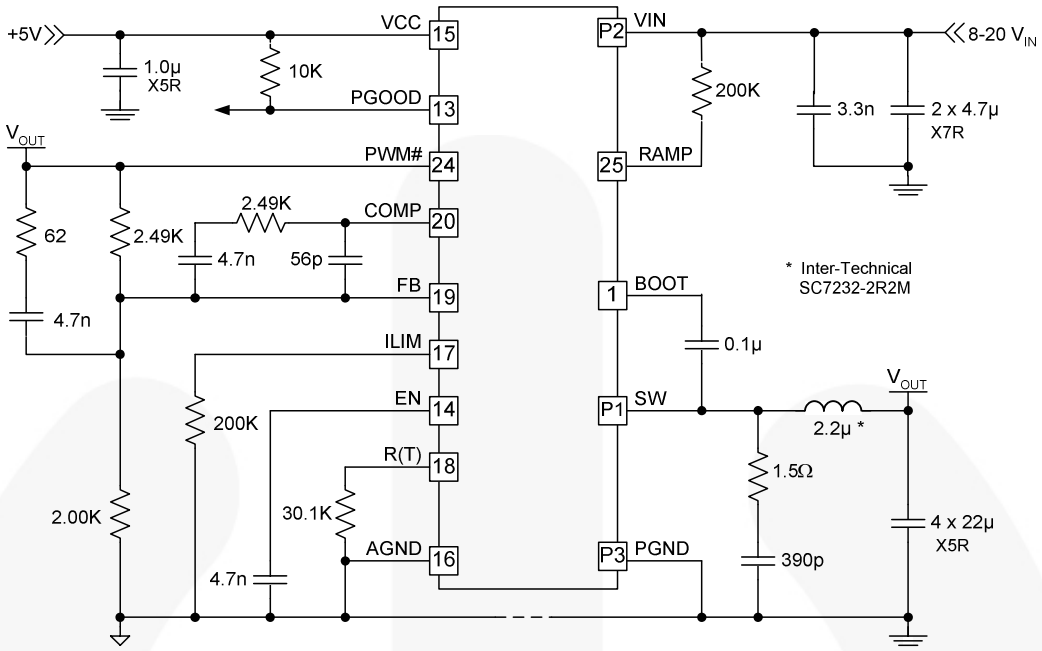

Figure 10. Application Circuit: 1.8V_{OUT}, 500KHz

Typical Performance Characteristics

Typical operating characteristics using the circuit shown in Figure 10. V_{IN}=16V, V_{CC}=5V, unless otherwise specified.

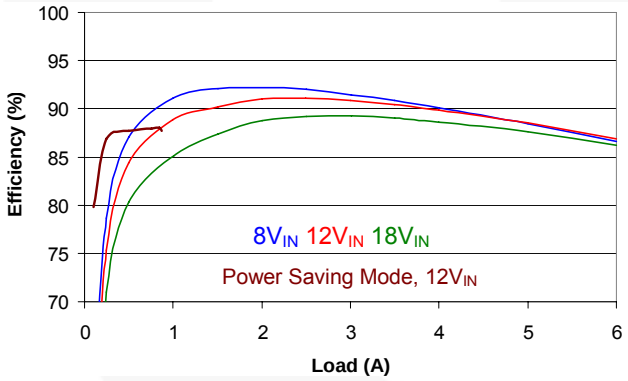

Figure 11. 1.8V_{OUT} Efficiency Over V_{IN} vs. Load

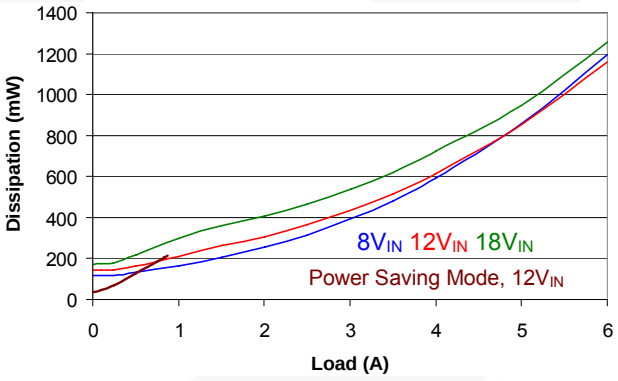

Figure 12. 1.8V_{OUT} Dissipation Over V_{IN} vs. Load

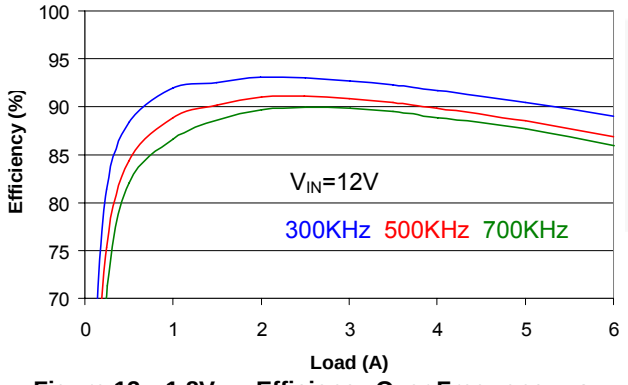

Figure 13. 1.8V_{OUT} Efficiency Over Frequency vs. Load (Circuit Value Changes)

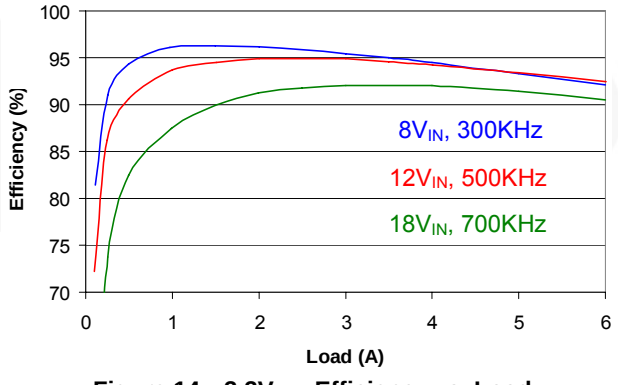

Figure 14. 3.3V_{OUT} Efficiency vs. Load (Circuit Value Changes)

Typical Performance Characteristics (Continued)

Typical operating characteristics using the circuit shown in Figure 10. V_{IN}=16V, V_{CC}=5V, unless otherwise specified.

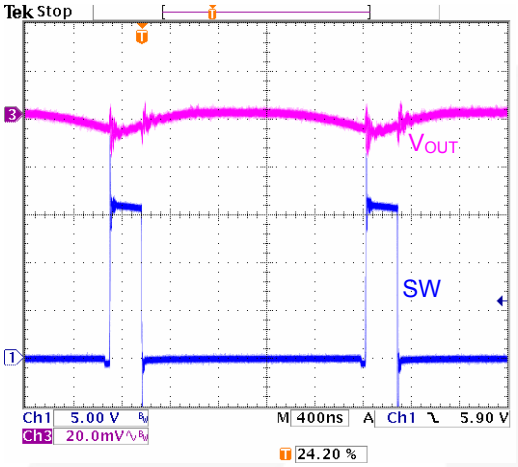

Figure 15. SW and V_{OUT} Ripple, 6A Load

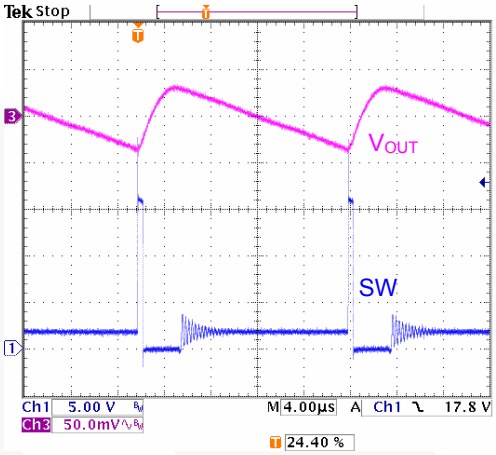

Figure 16. SW and V_{OUT} Ripple, 0.3A Load

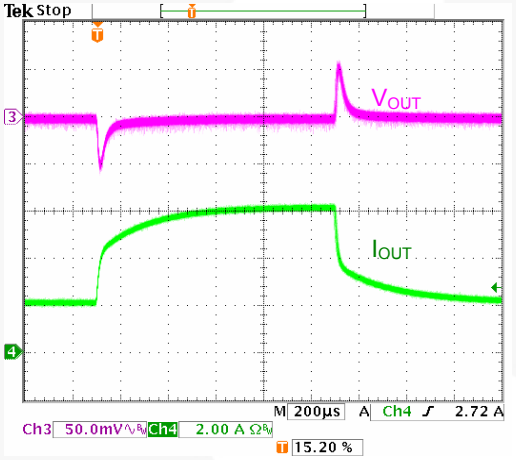

Figure 17. Transient Response, 2-6A Load

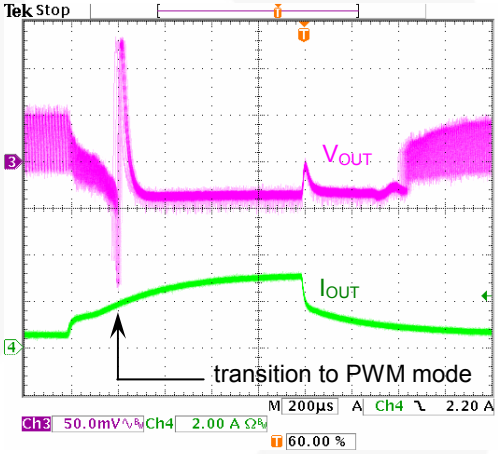

Figure 18. Transient Response, 0.3-3A Load

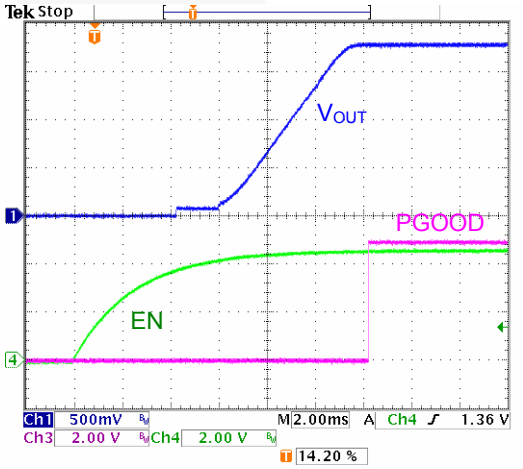

Figure 19. Start-Up, 3A Load

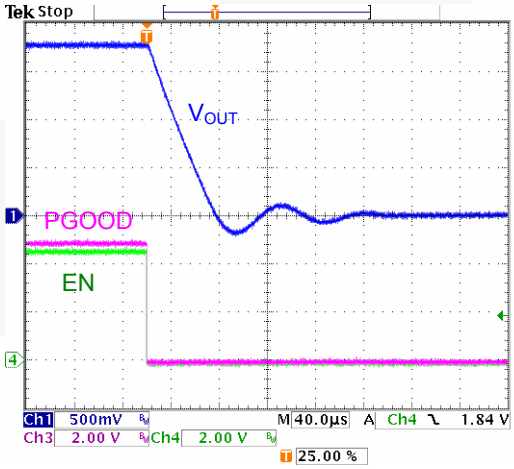

Figure 20. Shutdown, 3A Load

Circuit Description

Application Note *AN-6033 — FAN2106 Design Guide* includes a spreadsheet design aid to calculate external component values and verify loop stability given the following inputs:

- Output voltage
- Input voltage range
- Maximum output load current
- Maximum load transient current and maximum allowable output drop during load transient
- Maximum allowable output ripple
- Desired switching frequency

Download *AN-6033 — FAN2106 Design Guide* at:
http://www.fairchildsemi.com/an/AN/AN-6033.pdf

Initialization

Once V_{CC} exceeds the UVLO threshold and EN is HIGH, the IC checks for an open or shorted FB pin before releasing the internal soft-start ramp (SS).

If R1 is open, the error amplifier output (COMP) is forced LOW and no pulses are generated. After the SS ramp times out (T1.0), an under-voltage latched fault occurs.

If the parallel combination of R1 and R_{BIAS} is ≤ 1KΩ, the internal SS ramp is not released and the regulator does not start.

Soft-Start

Once SS has charged to 0.8V (T0.8), the output voltage is in regulation. Until SS reaches 1.0V (T1.0), the “Fault Latch” and power-saving mode operations are inhibited.

To avoid skipping the soft-start cycle, it is necessary to apply VIN before V_{CC} reaches its UVLO threshold.

Soft-start time is a function of oscillator frequency.

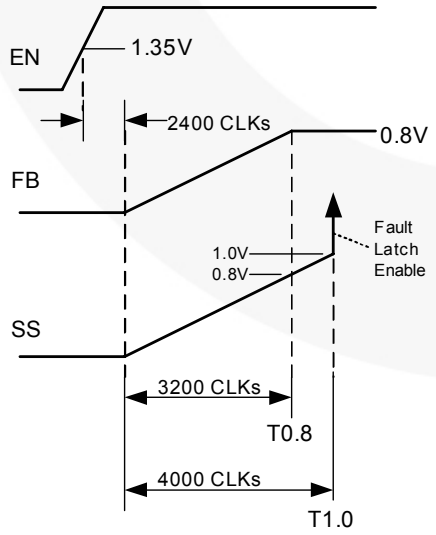

Figure 21. Soft-Start Timing Diagram

The regulator does not allow the low-side MOSFET to operate in full synchronous rectification mode until SS reaches 95% of V_{REF} (~0.76V). This prevents the regulator from discharging the output and ensures that inductor current does not "ratchet" up during the soft-start cycle.

V_{CC} UVLO or toggling the EN pin discharges the SS and resets the IC.

Bias Supply

The FAN2106 requires a 5V supply rail to bias the IC and provide gate-drive energy. Connect a ≥1.0µf X5R or X7R decoupling capacitor between VCC and PGND.

Since V_{CC} is used to drive the internal MOSFET gates, supply current is frequency and voltage dependent. Approximate V_{CC} current (I_{CC}) can be calculated using:

$$I_{CC(mA)} = 4.58 + [(\frac{V_{CC} - 5}{227} + 0.013) \bullet (F - 128)] \quad \text{EQ. 1}$$

where frequency (F) is expressed in KHz.

Setting the Output Voltage

The output voltage of the regulator can be set from 0.8V to 90% of V_{IN} by an external resistor divider (R1 and R_{BIAS} in Figure 1).

The internal reference is 0.8V with 650nA, sourced from the FB pin to ensure that, if the pin is open, the regulator does not start.

The external resistor divider is calculated using:

$$\frac{0.8V}{R_{BIAS}} = \frac{V_{OUT} - 0.8V}{R1} + 650nA \quad \text{EQ. 2}$$

Connect R_{BIAS} between FB and AGND.

To minimize noise pickup on the FB node, the values of R1 and R_{BIAS} should be selected to provide a minimum parallel impedance of 1KΩ.

Setting the Frequency

Oscillator frequency is determined by an external resistor, R_T, connected between the R(T) pin and AGND:

$$F_{(KHz)} = \frac{10^6}{(65 \bullet R_T) + 135} \quad \text{EQ. 3}$$

where R_T is expressed in KΩ.

$$R_{T(K\Omega)} = \frac{(10^6 / F) - 135}{65} \quad \text{EQ. 4}$$

where frequency (F) is expressed in KHz.

The regulator can not start if R_T is left open.

Calculating the Inductor Value

Typically the inductor is set for a ripple current (ΔI_L) of 10% to 35% of the maximum DC load. Regulators requiring fast transient response use a value on the high side of this range, while regulators that require very low output ripple and/or use high-ESR capacitors restrict allowable ripple current:

$$\Delta IL = \frac{V_{OUT} \bullet (1-D)}{L \bullet F} \quad \text{EQ. 5}$$

where F is the oscillator frequency, and

$$L = \frac{V_{OUT} \bullet (1-D)}{\Delta IL \bullet F} \quad \text{EQ. 6}$$

Refer to *AN-6033 — FAN2106 Design Guide* for additional information about inductor selection relative to power-saving mode performance.

Setting the Ramp Resistor Value

The internal ramp voltage excursion (ΔV_{RAMP}) during t_{ON} should be set to 0.6V. R_{RAMP} is approximately:

$$R_{RAMP(K\Omega)} = \frac{(V_{IN} - 1.8) \bullet V_{OUT}}{18x10^{-6} \bullet V_{IN} \bullet F} - 2 \quad \text{EQ. 7}$$

where frequency (F) is expressed in KHz.

Refer to *AN-6033 — FAN2106 Design Guide* to determine the optimal R_{RAMP} value.

Setting the Current Limit

The FAN2106 uses its internal low-side MOSFET as the current-sensing element. The current-limit threshold voltage (V_{ILIM}) is compared to the voltage drop across the low-side MOSFET, sampled at the end of each PWM off-time/cycle.

The default threshold (I_{LIM} open) is temperature compensated.

The 10µA current sourced from the ILIM pin can be used to establish a lower, temperature–dependent, current-limit threshold by connecting an external resistor (R_{ILIM}) to AGND:

$$R_{ILIM(K\Omega)} = 0.45 \bullet R_{DS} \bullet K_T \bullet (I_{OUT} - \frac{\Delta IL}{2}) + 142.5 \quad \text{EQ. 8}$$

where:

I = desired current limit set point in Amps,
R_{DS} is expressed in mΩ,
K_T = the normalized temperature coefficient of the low-side MOSFET (Q2) from Figure 8.

After 16 consecutive, pulse-by-pulse, current-limit cycles, the fault latch is set and the regulator shuts down. Cycling V_{CC} or EN restores operation after a normal soft-start cycle (refer to Auto-Restart section).

The over-current protection fault latch is active during the soft-start cycle.

Loop Compensation

The loop is compensated using a feedback network around the error amplifier. Figure 22 shows a complete Type-3 compensation network. Type-2 compensation eliminates R3 and C3.

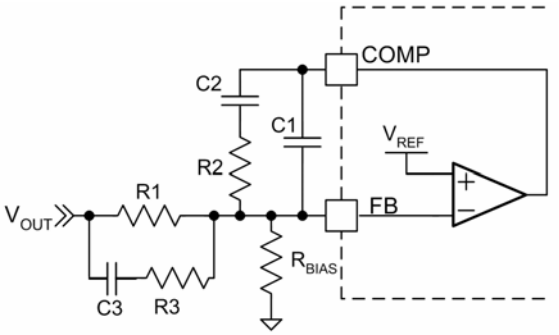

Figure 22. Compensation Network

Since the FAN2106 employs summing current-mode architecture, Type-2 compensation can be used for many applications. For applications that require wide loop bandwidth and/or use very low-ESR output capacitors, Type-3 compensation may be required. The AN-6033 spreadsheet calculator can be used to calculate these component values.

Protection

The converter output is monitored and protected against extreme overload, short-circuit, over-voltage, and under-voltage conditions.

An internal “Fault Latch” is set for any fault intended to shut down the IC. When the fault latch is set, the IC discharges V_{OUT} by enhancing the low-side MOSFET until FB<0.25V. The MOSFET is not turned on again unless FB>0.5V. This behavior discharges the output without causing undershoot (negative output voltage).

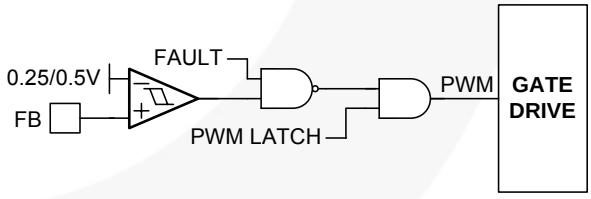

Figure 23. Latched Fault Response

Under-Voltage Shutdown

If FB remains below the under-voltage threshold for 16 consecutive clock cycles, the fault latch is set and the converter shuts down. This fault is prevented from setting the fault latch during soft-start.

Over-Voltage Protection / Shutdown

If FB exceeds 115% • V_{REF} for two consecutive clock cycles, the fault latch is set and shutdown occurs.

A shorted high-side MOSFET condition is detected when SW voltage exceeds ~0.7V while the low-side

MOSFET is fully enhanced. The fault latch is set immediately upon detection.

These two fault conditions are allowed to set the fault latch at any time, including during soft-start.

Auto-Restart

After a fault, EN is discharged with 1µA to a 1.1V threshold before the 800KΩ pull-up is restored. A new soft-start cycle begins when EN charges above 1.35V.

Depending on the external circuit, the FAN2106 can be provisioned to remain latched-off or automatically restart after a fault.

Table 1. Fault / Restart Provisioning

EN pin	Controller / Restart State
Pull to GND	OFF (disabled)
V_{CC}	No restart – latched OFF
Open	Immediate restart after fault
Cap to GND	New soft-start cycle after: t_{DELAY} (msec) = 3.9 • C(nf)

With EN left open, restart is immediate.

If auto-restart is not desired, tie the EN pin to the VCC pin or drive it with a logic gate to keep the 1µA current sink from discharging EN to 1.1V.

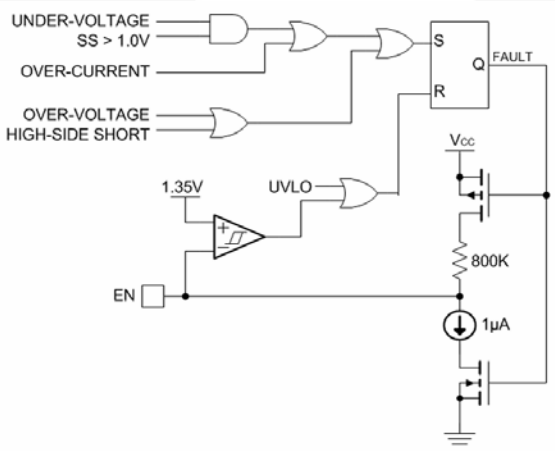

Figure 24. Fault Latch with Delayed Auto-Restart

Over-Temperature Protection

The chip incorporates an over-temperature protection circuit that sets the fault latch when a die temperature of about 150°C is reached. The IC is allowed to restart when the die temperature falls below 125°C.

Power Good (PGOOD) Signal

PGOOD is an open-drain output that asserts LOW when V_{OUT} is out of regulation, as measured at the FB pin. Thresholds are specified in the Electrical Specifications section. PGOOD does not assert HIGH until the fault latch is enabled (T1.0).

Power-Saving Mode

The FAN2106 maintains high efficiency at light load by changing to a discontinuous constant peak current, power-saving mode (PSM).

The transition to power-saving mode occurs when the load is $\leq \Delta I_L/2$ for eight consecutive clock cycles.

In power-saving mode, a constant peak inductor current (ΔI_{LPSM}) is generated each on-cycle. ΔI_{LPSM} is nominally 85% larger than PWM mode inductor ripple (ΔI_L).

During power-saving mode, the output is regulated to a slightly higher value than its set point, since the current pulse is triggered when FB crosses V_{REF}.

The IC is prevented from switching in the audible band. If the FB pin has not dropped to V_{REF} within 40µsec of the last pulse, the IC sinks current through the inductor to initiate a new cycle.

Transition back to PWM mode is achieved when a load transient causes the output voltage to drop 1.5% below its regulation point.

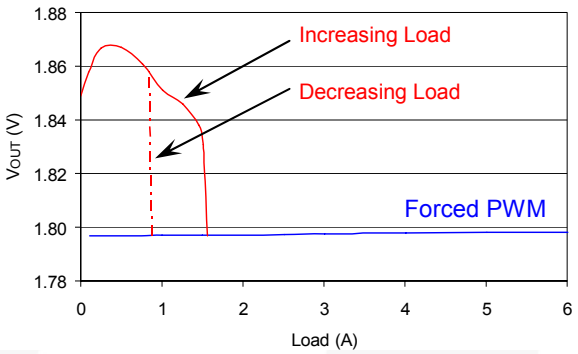

Figure 25. Power-Saving Mode Regulation
(Using Figure 10 Circuit)

Power-saving mode operation is defeated by connecting the PWM# pin to AGND, allowing only PWM operation. The PWM# pin has a 1µA pull-down. If <0.6V is detected, power-saving mode operation is disabled.

PCB Layout

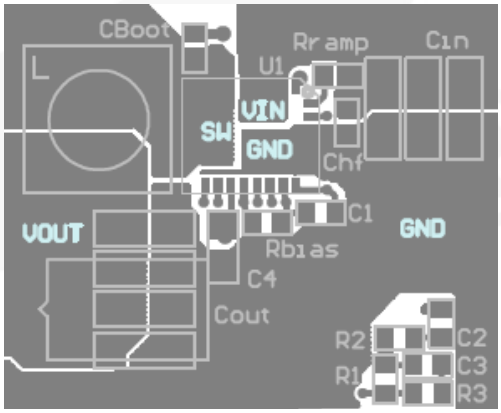

Figure 26. Recommended PCB Layout

Physical Dimensions

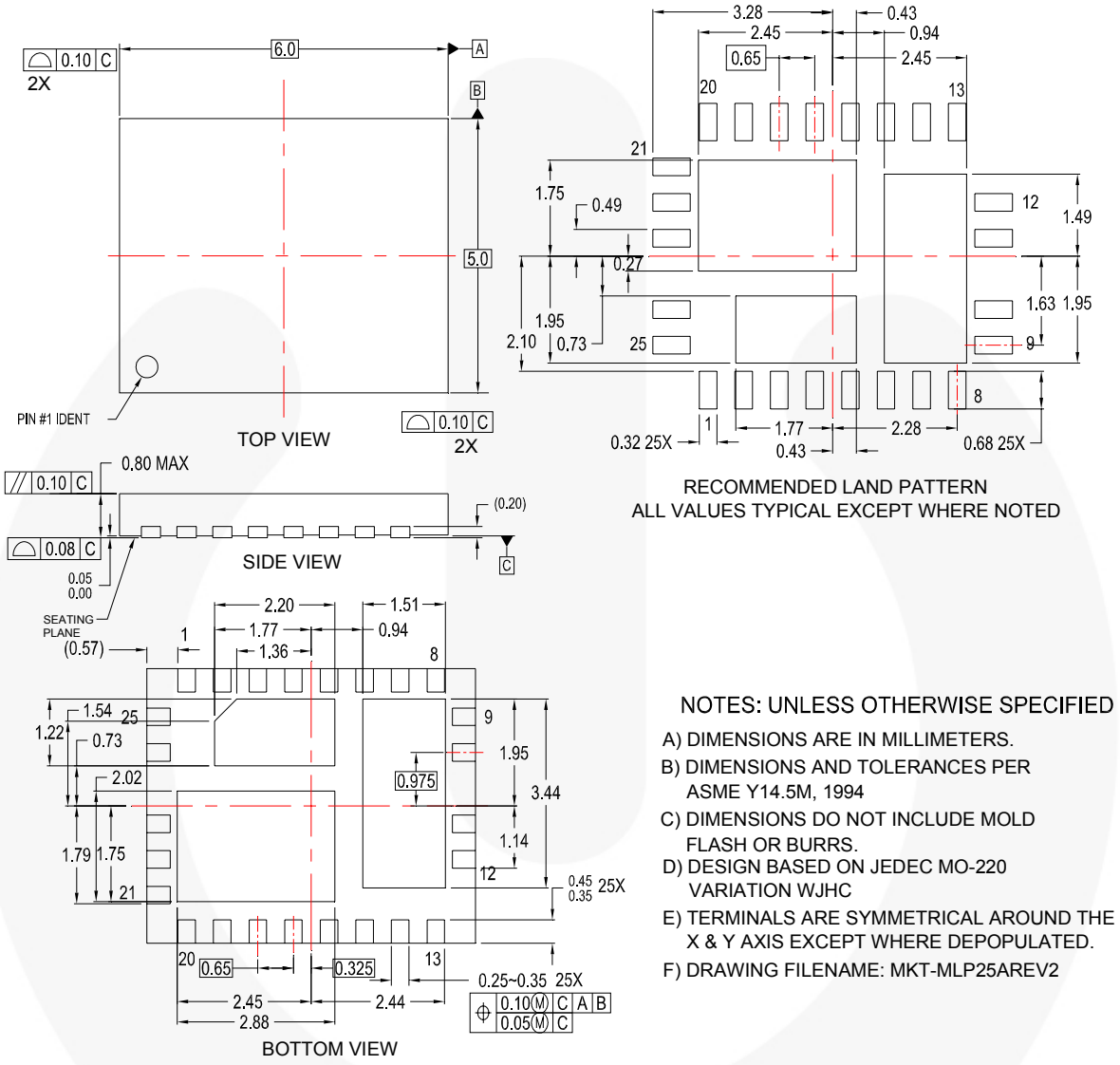

Figure 27. 5x6mm Molded Leadless Package (MLP)

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SuperSOT™-6
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