FAIRCHILD SEMICONDUCTOR®

September 2011

FAN2106 — TinyBuck™ 3-24V Input, 6A, High-Efficiency, Integrated Synchronous Buck Regulator

Features

- 6A Output Current
- Wide Input Range: 3V - 24V
- Output Voltage Range: 0.8V to 80% V_{IN}
- Over 95% Peak Efficiency
- 1% Reference Accuracy Over Temperature
- Programmable Frequency Operation: 200KHz to 600KHz
- Fully Synchronous Operation with Integrated Schottky Diode on Low-Side MOSFET Boosts Efficiency
- Internal Bootstrap Diode
- Internal Soft-Start
- Power-Good Signal
- Starts on Pre-Biased Outputs
- Accepts Ceramic Capacitors on Output
- External Compensation for Flexible Design
- Programmable Current Limit
- Under-Voltage, Over-Voltage, and Thermal Protections
- 5x6mm, 25-Pin, 3-Pad MLP Package

Applications

- Servers & Telecom
- Graphics Cards & Displays
- Computing Systems
- Point-of-Load Regulation
- Set-Top Boxes & Game Consoles

Description

The FAN2106 TinyBuck™ is a highly efficient, small-footprint, constant-frequency, 6A, integrated synchronous buck regulator.

The FAN2106 contains both synchronous MOSFETs and a controller/driver with optimized interconnects in one package, which enables designers to solve high-current requirements in a small area with minimal external components. Integration helps to minimize critical inductances, making component layout simpler and more efficient compared to discrete solutions.

The FAN2106 provides for external loop compensation, programmable switching frequency, and current limit. These features allow design flexibility and optimization. High-frequency operation allows for all-ceramic solutions.

The summing current-mode modulator uses lossless current sensing for current feedback and over-current protection. Voltage feedforward helps operation over a wide input voltage range.

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

Output over-voltage, under-voltage, over-current, and thermal shutdown protections help protect the device from damage during fault conditions. FAN2106 prevents pre-biased output discharge during startup in point-of-load applications.

Related Resources

- *AN-8022 — TinyCalc™ Calculator User Guide*
- *TinyCalc™ Calculator Design Tool*

Ordering Information

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

Typical Application Diagram

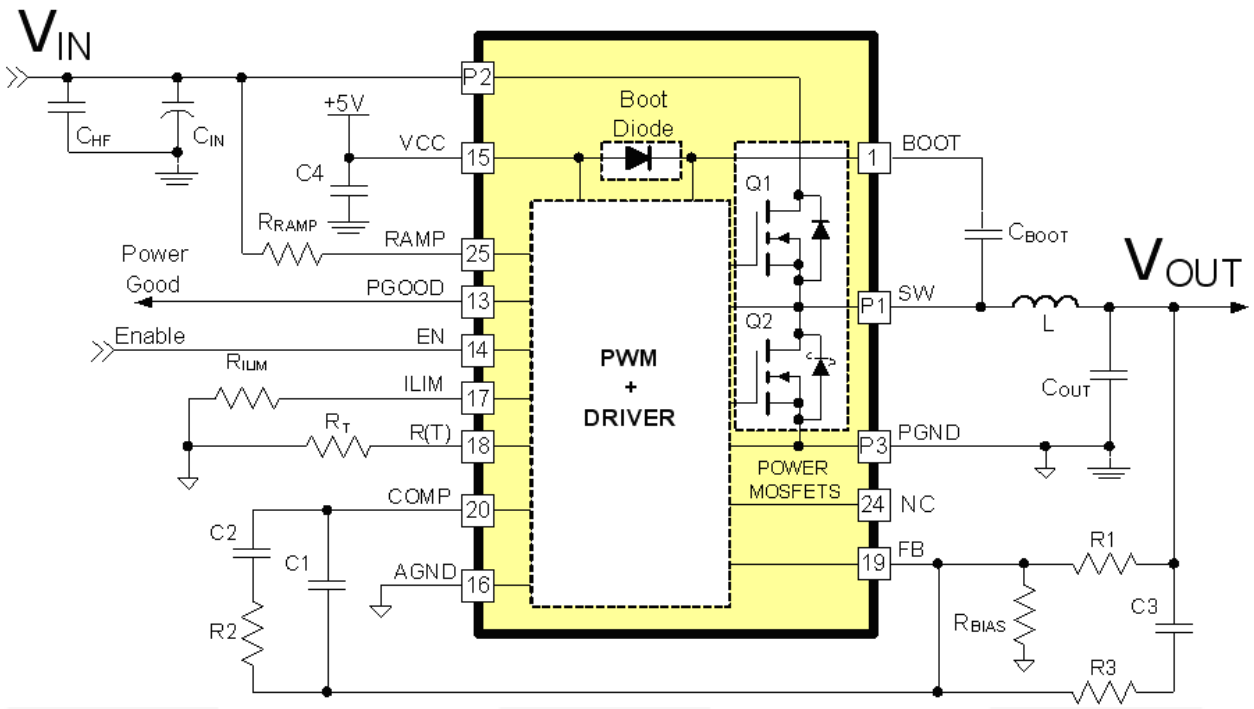

Figure 1. Typical Application

Block Diagram

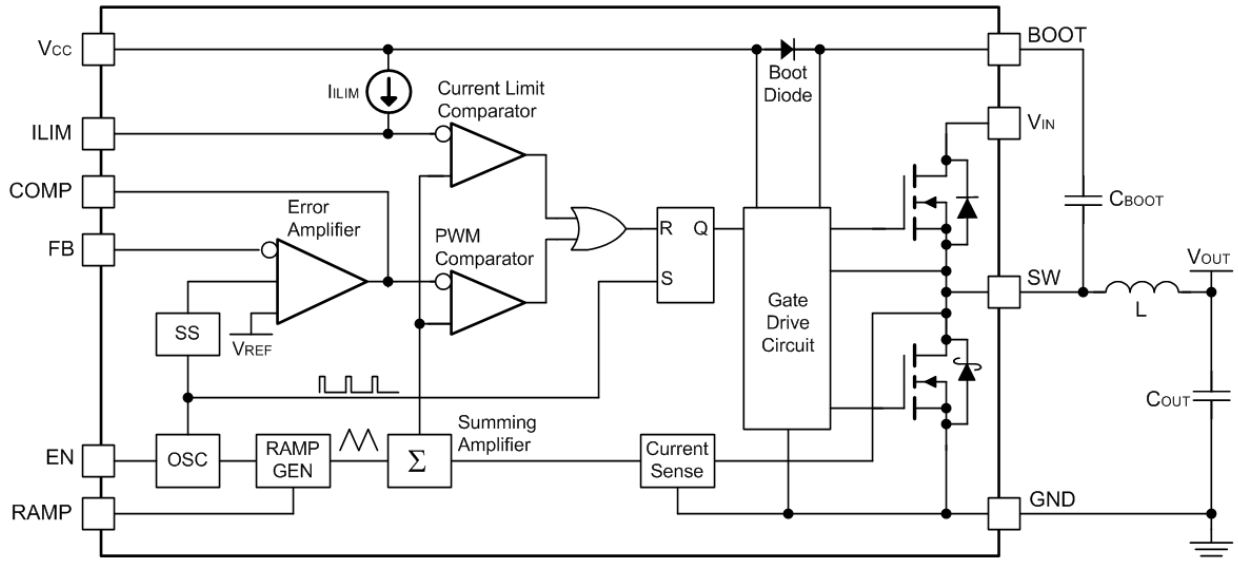

Figure 2. Block Diagram

Pin Configuration

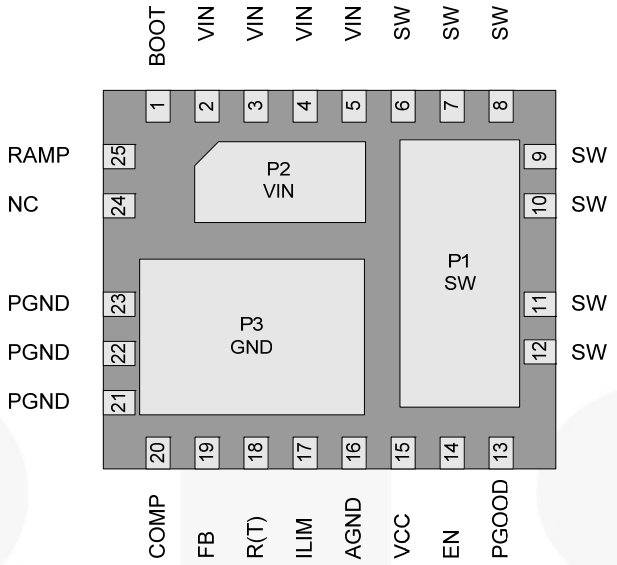

Figure 3. MLP 5x6mm Pin Configuration (Bottom View)

Pin Definitions

Pin #	Name	Description
P1, 6-12	SW	**Switching Node**. Junction of high-side and low-side MOSFETs.
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 the limits specified in electrical specs. 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. This pin should be decoupled to AGND through a >1µF X5R/X7R capacitor.
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	NC	**No Connect**. This pin is not used.
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 < 20ns, f ≤ 600KHz)	-5.0	30.0	
All other pins		-0.3	V_{CC}+0.3	V
ESD	Human Body Model, JEDEC JESD22-A114	2.0		kV
	Charged Device Model, JEDEC JESD22-C101	2.5		

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	FAN2106MPX	-10		+85	℃
		FAN2106EMPX	-40		+85	
T_J	Junction Temperature				+125	℃
f_{SW}	Switching Frequency		200		600	KHz

Thermal Information

Symbol	Parameter		Min.	Typ.	Max.	Unit
T_{STG}	Storage Temperature		-65		+150	℃
T_L	Lead Soldering Temperature, 10 Seconds				+300	℃
θ_{JC}	Thermal Resistance: Junction-to-Case	P1 (Q2)		4		℃/W
		P2 (Q1)		7		
		P3		4		
$\theta_{J\text{-}PCB}$	Thermal Resistance: Junction-to-Mounting Surface			35(1)		℃/W
P_D	Power Dissipation, T_A = 25℃				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

Electrical specifications are the result of using the circuit shown in Figure 1 with V_{IN} = 12V, 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
V_{CC} UVLO Threshold	Rising V_{CC}	4.1	4.3	4.5	V
	Hysteresis		300		mV
Oscillator					
Frequency	R_T = 50KΩ	255	300	345	KHz
	R_T = 24KΩ	540	600	660	KHz
Minimum On-Time(2)			50	65	ns
Ramp Amplitude, Peak-to-Peak	16V_{IN}, 1.8V_{OUT}, R_T = 30KΩ, R_{RAMP} = 200KΩ		0.53		V
Minimum Off-Time(2)			100	150	ns
Reference					
Reference Voltage (V_{FB})(3)	FAN2106MPX, T_A = 25°C	794	800	806	mV
	FAN2106EMPX, T_A = 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, T_A = 25°C	-850	-650	-450	nA
Protection and Shutdown					
Current Limit	R_{ILIM} Open, f_{SW} = 500KHz, V_{OUT} = 1.8V, R_{RAMP} = 200KΩ, 16 Consecutive Cycles	6	8	10	A
I_{LIM} Current	V_{CC} = 5V, T_A = 25°C	-11	-10	-9	µA
Over-Temperature Shutdown	Internal IC 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
Soft-Start					
V_{OUT} to Regulation (T0.8)	Frequency = 600KHz		5.3		ms
Fault Enable/SSOK (T1.0)			6.7		ms

Continued on the following page…

Electrical Specifications (Continued)

Electrical specifications are the result of using the circuit shown in Figure 1 with V_{IN}= 12V, unless otherwise noted.

Parameter	Conditions	Min.	Typ.	Max.	Unit
Control Functions					
EN Threshold, Rising	V_{CC} = 5V		1.35	2.00	V
EN Hysteresis	V_{CC} = 5V		250		mV
EN Pull-Up Resistance	V_{CC} = 5V		800		KΩ
EN Discharge Current	Auto-Restart Mode, V_{CC} = 5V		1		µA
FB OK Drive Resistance				800	Ω
PGOOD Threshold (Compared to V_{REF})	FB < V_{REF}, 2 Consecutive Clock Cycles	-14	-11	-8	%V_{REF}
	FB > V_{REF}, 2 Consecutive Clock Cycles	+7	+10	+13	%V_{REF}
PGOOD Output Low	$I_{OUT} \leq$ 2mA			0.4	V

Note:

2. Specifications guaranteed by design and characterization; not production tested.
3. *See Figure 4 for Temperature Coefficient*

Typical Characteristics

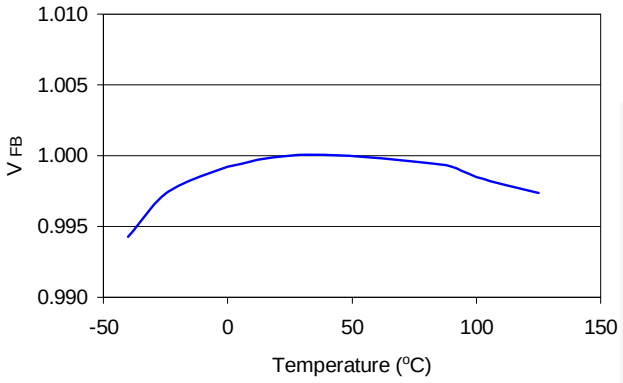

Figure 4. Reference Voltage (V_{FB}) vs. Temperature, Normalized

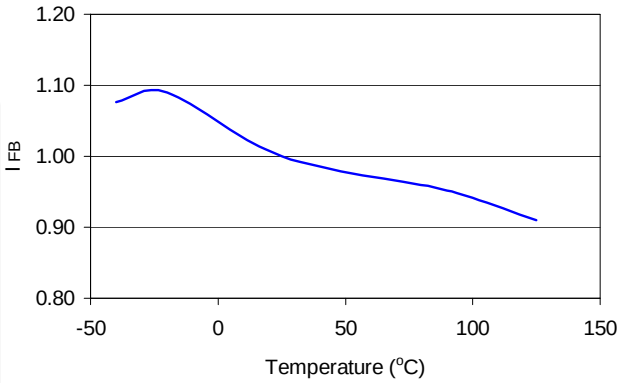

Figure 5. Reference Bias Current (I_{FB}) vs. Temperature, Normalized

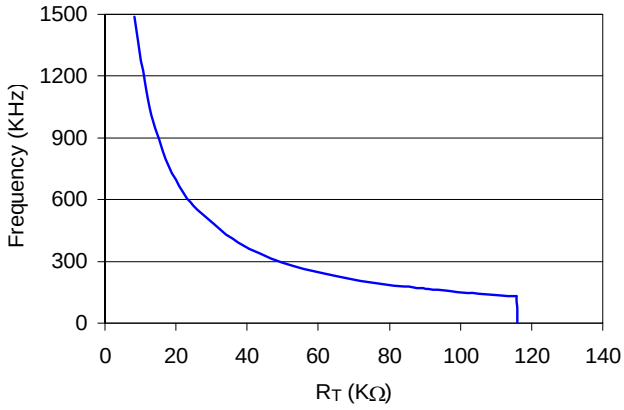

Figure 6. Frequency vs. R_T

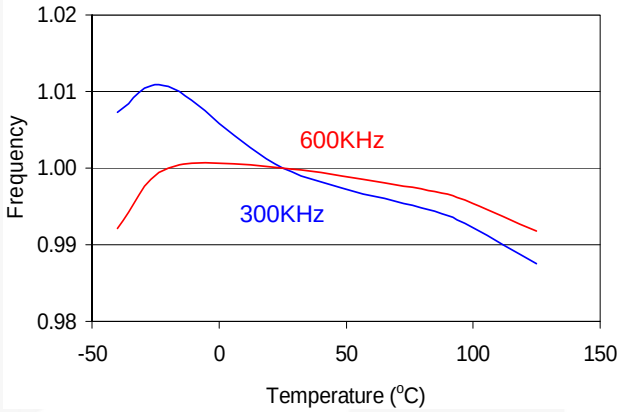

Figure 7. Frequency vs. Temperature, Normalized

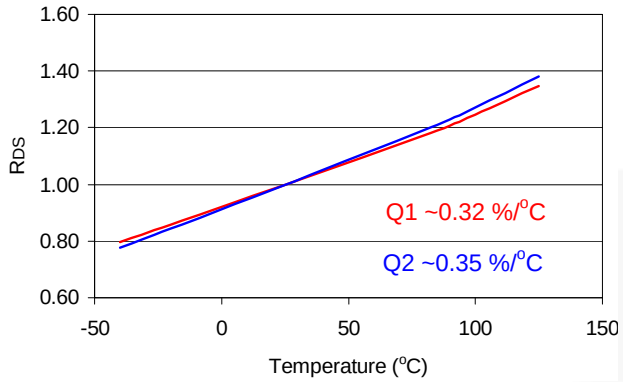

Figure 8. R_{DS} vs. Temperature, Normalized (V_{CC} = V_{GS} = 5V)

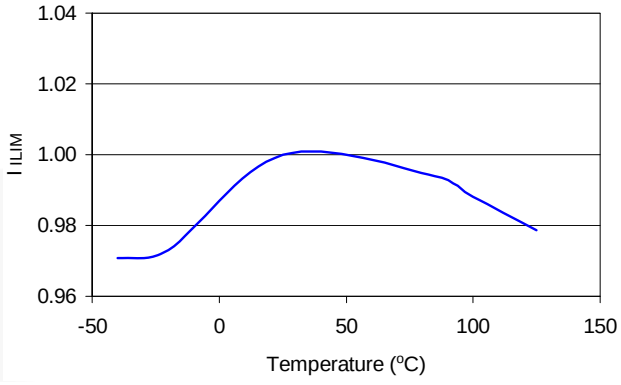

Figure 9. I_{LIM} Current (I_{ILIM}) vs. Temperature, Normalized

Application Circuit

FAN2106

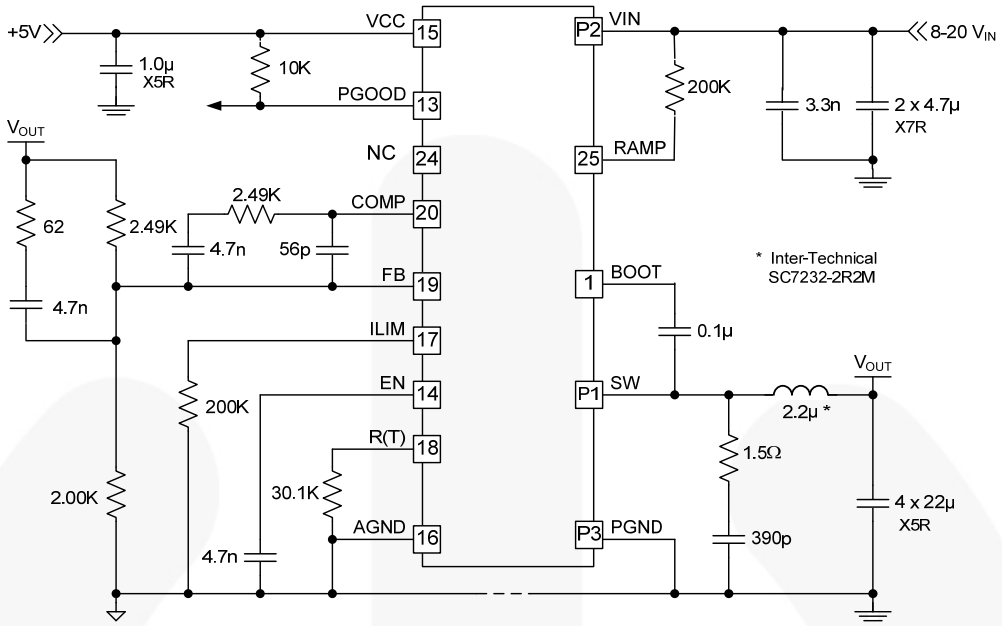

Figure 10. Application Circuit: 1.8V_{OUT}, 500KHz

Typical Performance Characteristics

Typical operating characteristics using the circuit shown in Figure 10. V_{IN}=12V, V_{CC}=5V, unless otherwise specified.

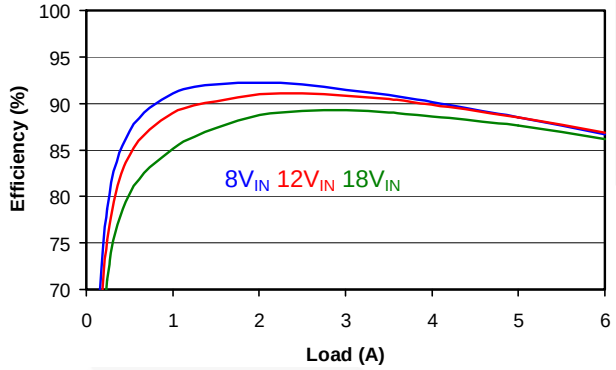

Figure 11. 1.8V_{OUT} Efficiency Over V_{IN} vs. Load

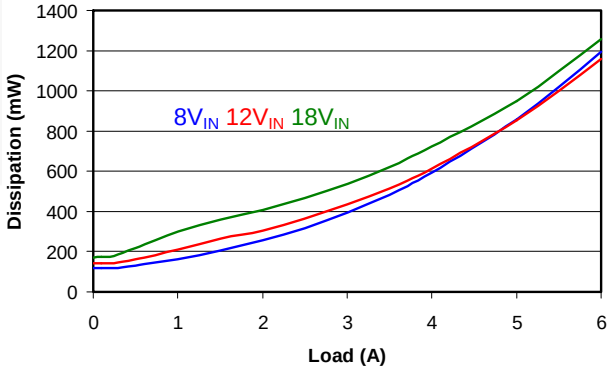

Figure 12. 1.8V_{OUT} Dissipation Over V_{IN} vs. Load

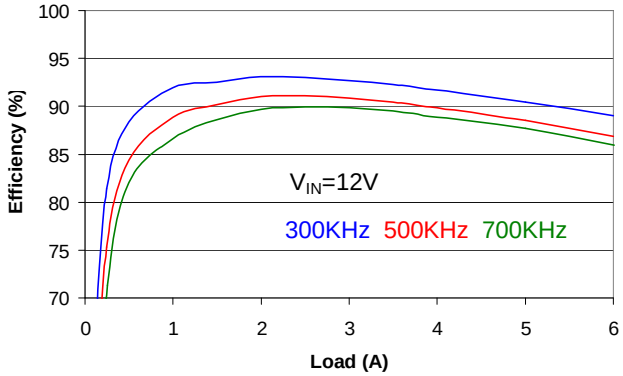

Figure 13. 1.8V_{OUT} Efficiency Over Frequency vs. Load (Circuit Value Changes)

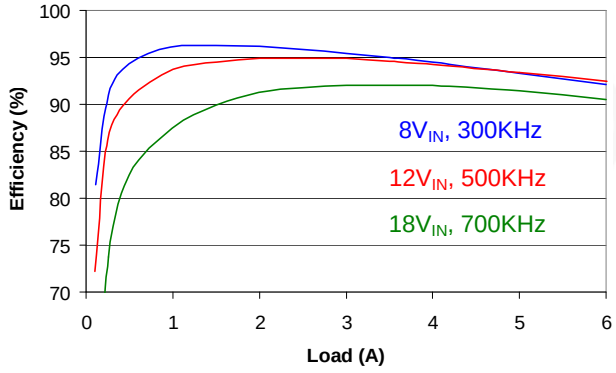

Figure 14. 3.3V_{OUT} Efficiency vs. Load (Circuit Value Changes)

Typical Performance Characteristics (Continued)

Typical operating characteristics using the circuit shown in Figure 10. V_{IN}=12V, V_{CC}=5V, unless otherwise specified.

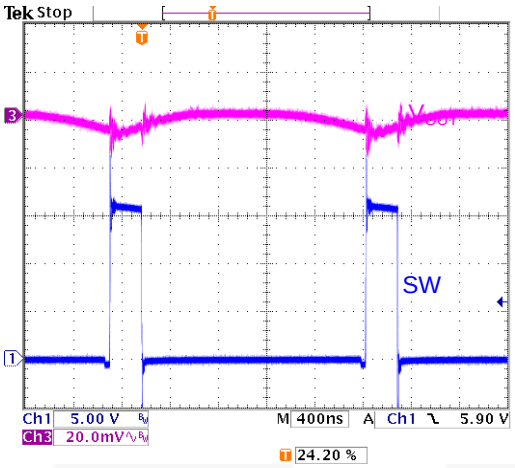

Figure 15. SW and V_{OUT} Ripple, 6A Load

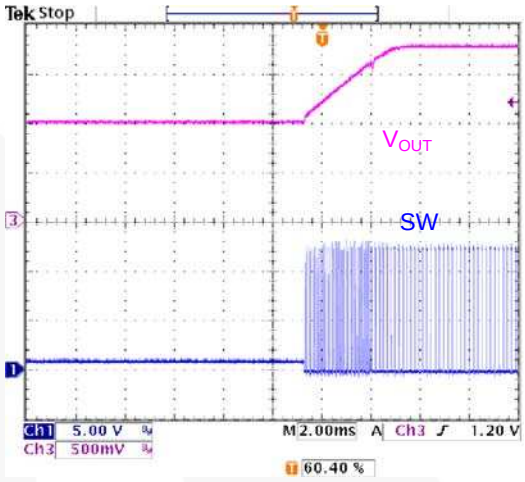

Figure 16. Startup with 1V Pre-Bias on V_{OUT}

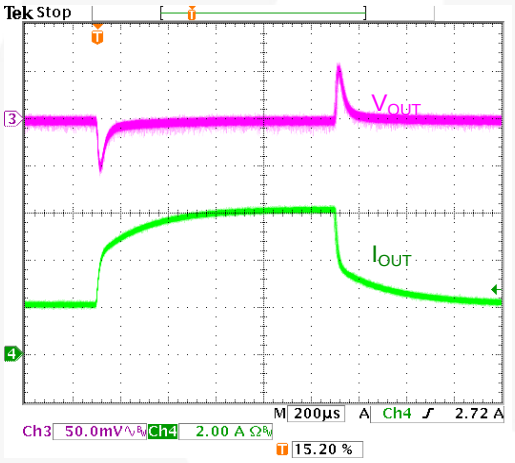

Figure 17. Transient Response, 2-6A Load

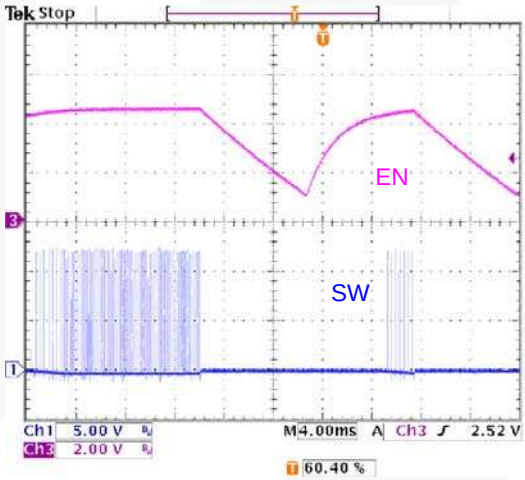

Figure 18. Re-Start on Fault

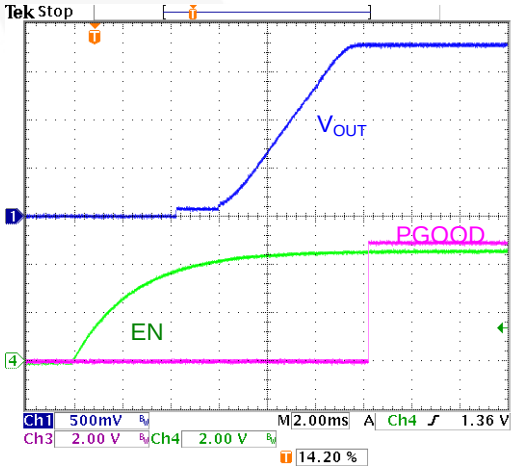

Figure 19. Startup, 3A Load

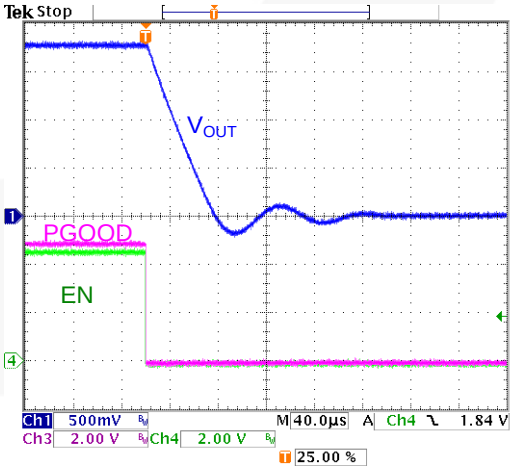

Figure 20. Shutdown, 3A Load

Circuit Description

PWM Generation

Refer to Figure 2 for the PWM control mechanism. FAN2106 uses the summing-mode method of control to generate the PWM pulses. An amplified current-sense signal is summed with an internally generated ramp and the combined signal is compared with the output of the error amplifier to generate the pulsewidth to drive the high-side MOSFET. Sensed current from the previous cycle is used to modulate the output of the summing block. The output of the summing block is also compared against a voltage threshold set by the R_{LIM} resistor to limit the inductor current on a cycle-by-cycle basis. The R_{RAMP} resistor helps set the charging current for the internal ramp and provides input voltage feed-forward function. The controller facilitates external compensation for enhanced flexibility.

Initialization

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

If the parallel combination of R1 and R_{BIAS} is $\leq 1K\Omega$, the internal SS ramp is not released and the regulator does not start.

Enable

FAN2106 has an internal pull-up to the ENABLE (EN) pin so that the IC is enabled once V_{CC} exceeds the UVLO threshold. Connecting a small capacitor across EN and AGND delays the rate of voltage rise on the EN pin. The EN pin also serves for the restart whenever a fault occurs *(refer to the Auto-Restart section)*. If the regulator is enabled externally, the external EN signal should go HIGH only after V_{CC} is established. For applications where such sequencing is required, FAN2106 can be enabled (after the V_{CC} comes up) with external control, as shown in Figure 21.

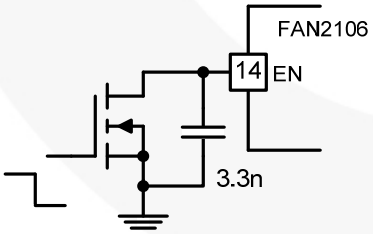

Figure 21. Enabling with External Control

Soft-Start

Once internal SS ramp has charged to 0.8V (T0.8), the output voltage is in regulation. Until SS ramp reaches 1.0V (T1.0), the fault latch is inhibited.

To avoid skipping the soft-start cycle, it is necessary to apply V_{IN} before V_{CC} reaches its UVLO threshold. Normal sequence for powering up would be VIN→VCC→EN.

Soft-start time is a function of switching frequency.

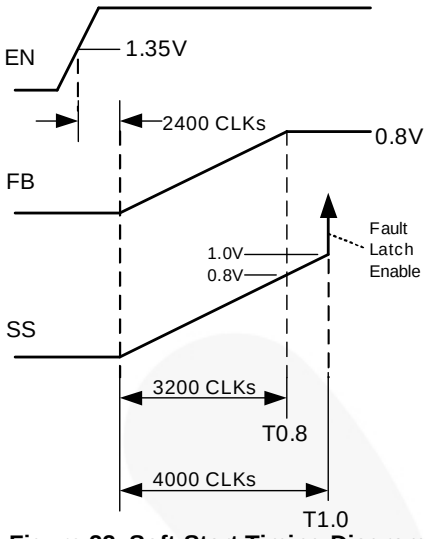

Figure 22. Soft-Start Timing Diagram

Cycling V_{CC} or the EN pin discharges the internal SS and resets the IC. In applications where external EN signal is used, V_{IN} and V_{CC} should be established before the EN signal comes up to prevent skipping the soft-start function.

Startup on Pre-Bias

The regulator does not allow the low-side MOSFET to operate in full synchronous rectification mode until internal SS ramp reaches 95% of V_{REF} (~0.76V). This helps the regulator start on a pre-biased output and ensures that the pre-biased outputs are not discharged during soft-start.

Protections

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

Under-Voltage Shutdown

If the voltage on the FB pin remains below the under-voltage threshold for 16 consecutive clock cycles, the fault latch is set and the converter shuts down. This protection is not active until the internal SS ramp reaches 1.0V during soft-start.

Over-Voltage Protection

If voltage on the FB pin exceeds 115% of 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.

The OV and high-side short fault protections are active all the time, including during soft-start.

Over-Temperature Protection (OTP)

The chip incorporates an over-temperature protection circuit that sets the fault latch when a die temperature of about 150℃ is reached. The IC restarts when the die temperature falls below 125℃.

Auto-Restart

After a fault, EN pin is discharged by a 1µA current sink to a 1.1V threshold before the internal 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 configured to remain latched-off or to automatically restart after a fault.

Table 1. Fault / Restart Configurations

EN Pin	Controller / Restart State
Pull to GND	OFF (Disabled)
Pull-up to V_{CC} with 100K	No Restart – Latched OFF (After V_{CC} Comes Up)
Open	Immediate Restart After Fault
Cap. to GND	New Soft-Start Cycle After: t_{DELAY} (ms)=3.9 • C(nf)

When EN is left open, restart is immediate.

If auto-restart is not desired, tie the EN pin to the VCC pin or pull it HIGH after V_{CC} comes up with a logic gate to keep the 1µA current sink from discharging EN to 1.1V. Figure 23 shows one method to pull up EN to V_{CC} for a latch configuration.

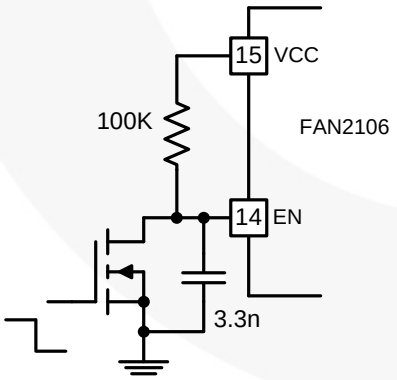

Figure 23. Enable Control with Latch Option

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) *(see Figure 22)*.

Application Information

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:

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

where frequency (f) is expressed in KHz.

Setting the Output Voltage

The output voltage of the regulator can be set from 0.8V to 80% of V_{IN} by an external resistor divider (R1 and R_{BIAS} in Figure 1). For output voltages > 5V, output current rating may need to be de-rated depending upon the ambient temperature, power dissipated in the package and the PCB layout.

The external resistor divider is calculated using:

$$\frac{0.8V}{R_{BIAS}} = \frac{V_{OUT} - 0.8V}{R1} + 650nA \quad (2)$$

Connect R_{BIAS} between FB and AGND.

If R1 is open (see Figure 1), the output voltage is not regulated eventually causing a latched fault after the soft start is complete (T1.0)

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

Setting the Switching Frequency

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

$$R_{T(K\Omega)} = \frac{(10^6 / f) - 135}{65} \quad (3)$$

where R_T is in KΩ and frequency (f) is in KHz.

The regulator cannot start if R_T is left open.

Calculating the Inductor Value

Typically the inductor value is chosen based on ripple current (ΔIL), which is chosen between 10 to 35% of the maximum DC load. Regulator designs that require fast transient response use a higher ripple-current setting, while regulator designs that require higher efficiency keep ripple current on the low side and operate at a lower switching frequency. The inductor value is calculated by the following formula:

$$\Delta I_L = \frac{V_{OUT} \bullet (1 - D)}{L \bullet f} \quad (4)$$

where f is the switching frequency.

Setting the Ramp Resistor Value

R_{RAMP} resistor plays a critical role in the design by providing charging current to the internal ramp capacitor and also serving as a means to provide input voltage feedforward.

R_{RAMP} is calculated by the following formula:

$$R_{RAMP(K\Omega)} = \frac{(V_{IN} - 1.8) \bullet V_{OUT}}{(18) \bullet V_{IN} \bullet f \bullet 10^{-6}} - 2 \quad (5)$$

where frequency (f) is expressed in KHz.

For wide input operation, first calculate R_{RAMP} for the minimum and maximum input voltage conditions and use larger of the two values calculated.

In all applications, current through the R_{RAMP} pin must be greater than 10µA from the equation below for proper operation:

$$\frac{V_{IN} - 1.8}{R_{RAMP} + 2} \geq 10\mu A \quad (6)$$

If the calculated R_{RAMP} values in Equation (5) result in a current less than 10µA, use the R_{RAMP} value that satisfies Equation (6). In applications with large input ripple voltage, the R_{RAMP} resistor should be adequately decoupled from the input voltage to minimize ripple on the RAMP pin**.**

Setting the Current Limit

There are two levels of current-limit thresholds. The first level of protection is through an internal default limit set at the factory to limit output current beyond normal usage levels. The second level of protection is set externally at the ILIM pin by connecting a resistor (R_{ILIM}) between ILIM and AGND. Current-limit protection is enabled whenever the lower of the two thresholds is reached (*see Figure 24*). FAN2106 uses its internal low-side MOSFET for current-sensing. The current-limit threshold voltage (V_{ILIM}) is compared to a scaled version of voltage drop across the low-side MOSFET sampled at the end of each PWM off-time/cycle. The internal default threshold (with I_{LIM} open) is temperature compensated.

For a given R_{ILIM} and R_{RAMP} setting, the current limit point varies slightly in an inverse relationship with respect to input voltage (V_{IN}).

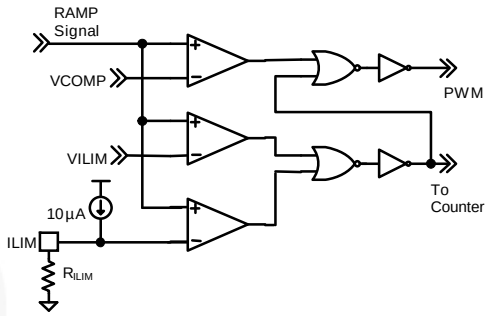

Figure 24.ILIM Network

The ILIM pin can source a 10µA current that can be used to establish a lower, temperature-dependent, current-limit threshold by connecting an external resistor (R_{ILIM}) to AGND. R_{ILIM} can be approximated with the equation:

$$R_{ILIM(K\Omega)} = 0.45 \bullet R_{DS} \bullet (1 + K_T) \bullet (I_{OUT} - \frac{\Delta I_L}{2}) + 142.5 \quad (7)$$

where:
I is desired current limit set point in Amps;
R_{DS} is expressed in mΩ; and
K_T is the normalized temperature coefficient of the low-side MOSFET (Q2) from Figure 8. Use 0.35 in equation.

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 the Auto-Restart section)*.

The over-current protection fault latch is active during the soft-start cycle. Use 1% resistor for R_{ILIM}.

Loop Compensation

The loop is compensated using a feedback network around the error amplifier. Figure 25 shows a complete Type-3 compensation network. For Type-2 compensation, eliminate R3 and C3.

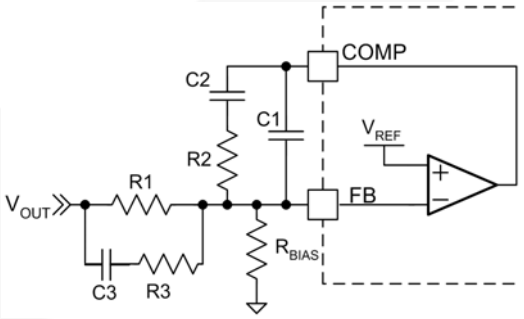

Figure 25. Compensation Network

Since the FAN2106 employs a 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.

R_{RAMP} also provides feedforward compensation for changes in V_{IN}. With a fixed R_{RAMP} value, the modulator gain increases as V_{IN} is reduced; this could make it difficult to compensate the loop. For low-input-voltage-range designs (3V to 8V), R_{RAMP} and the compensation component values are different compared to designs with V_{IN} between 8V and 24V.

Application note AN-8022 (TinyCalc™) can be used to calculate the compensation components.

Recommended PCB Layout

Good PCB layout and careful attention to temperature rise is essential for reliable operation of the regulator. Four-layer PCB with two-ounce copper on the top and bottom sides and thermal vias connecting the layers are recommended. Keep power traces wide and short to minimize losses and ringing. Do not connect AGND to PGND below the IC. Connect the AGND pin to PGND at the output OR to the PGND plane.

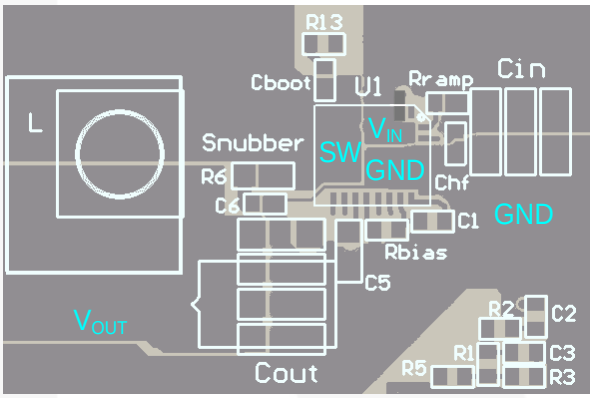

Figure 26. Recommended PCB Layout

Physical Dimensions

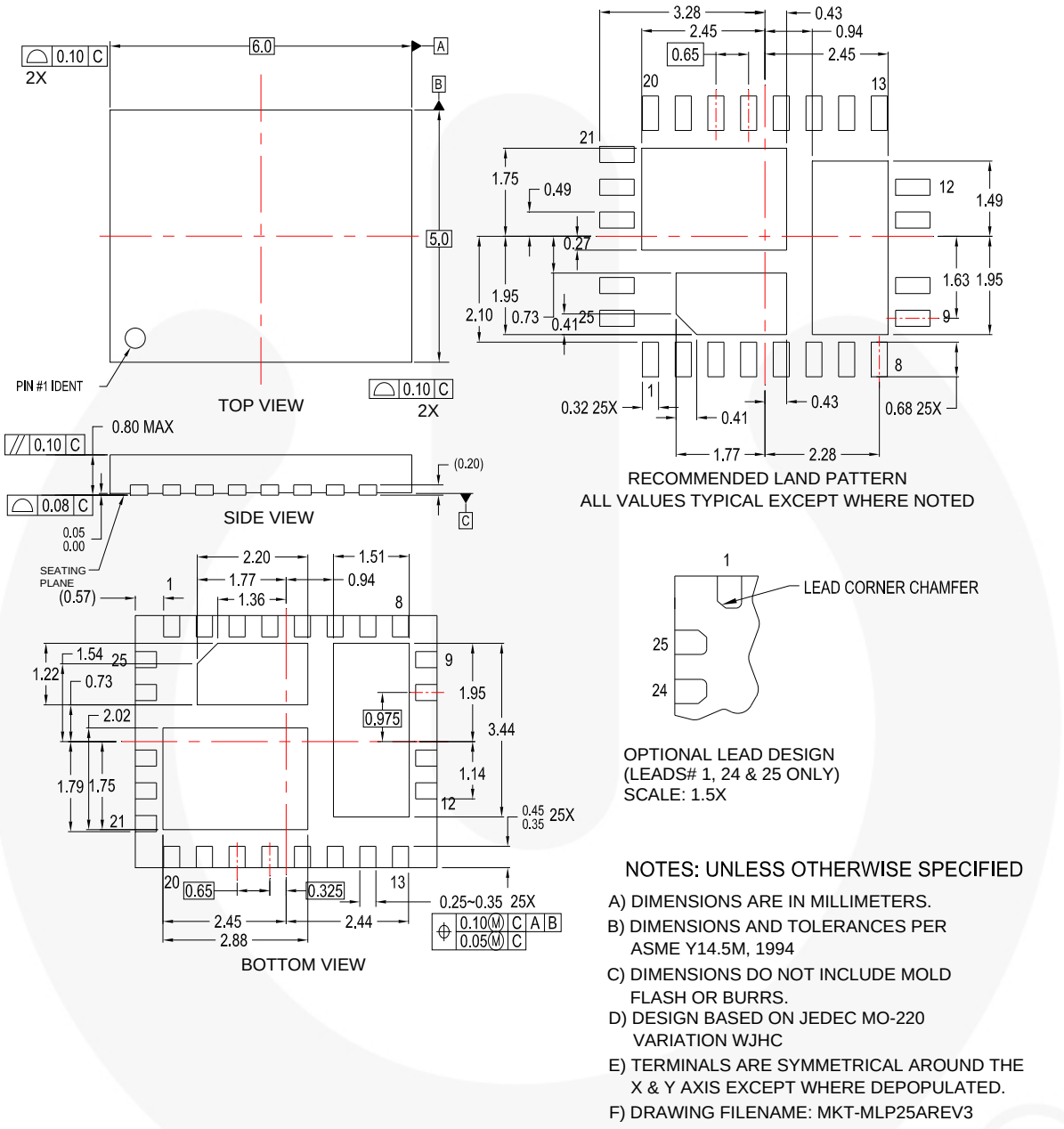

Figure 27. 5x6mm Molded Leadless Package (MLP)

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