FAIRCHILD SEMICONDUCTOR®

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FAN2103 — TinyBuck™ 3 A, 24 V Input, Integrated Synchronous Buck Regulator

Features

- 3 A Output Current
- Over 95% Efficiency
- Fully Synchronous Operation with Integrated Schottky Diode on Low-side MOSFET Boosts Efficiency
- Programmable Frequency Operation (200 KHz to 600 KHz)
- Power-good Signal
- Accepts Ceramic Capacitors on Output
- External Compensation for Flexible Design
- Wide Input Range: 3 V to 24 V
- Output Voltage Range: 0.8 V to 90%V_{IN}
- Input Under-Voltage Lockout
- Programmable Over-Current Limit
- Under-Voltage, Over-Voltage, and Thermal Protections
- 5x6 mm, 25-pin, 3-Pad MLP

Applications

- Graphics Cards
- Battery-powered Equipment
- Set-top Boxes
- Point-of-load Regulation
- Servers

Description

The FAN2103 TinyBuck™ is an easy-to-use, cost- and space-efficient, 3 A synchronous buck solution. It enables designers to solve high current requirements in a small area with minimal external components.

External compensation, programmable switching frequency, and current limit features allow for design optimization and flexibility.

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 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, and thermal shutdown protections plus power-good, help protect the devices from damage during fault conditions.

Related Application Notes

- *TinyCalc™ Design Tool*
- *AN-6033 — TinyCalc™ Design Tool Guide*
- *AN-5067 – PCB Land Pattern Design and Surface Mount Guidelines for MLP Packages*

Ordering Information

Part Number	Operating Temperature Range	Package	Packing Method
FAN2103MPX	-10°C to 85°C	25-Pin Molded Leadless Package (MLP) 5x6 mm	Tape and Reel
FAN2103EMPX	-40°C to 85°C	25-Pin Molded Leadless Package (MLP) 5x6 mm	Tape and Reel

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Typical Application Diagram

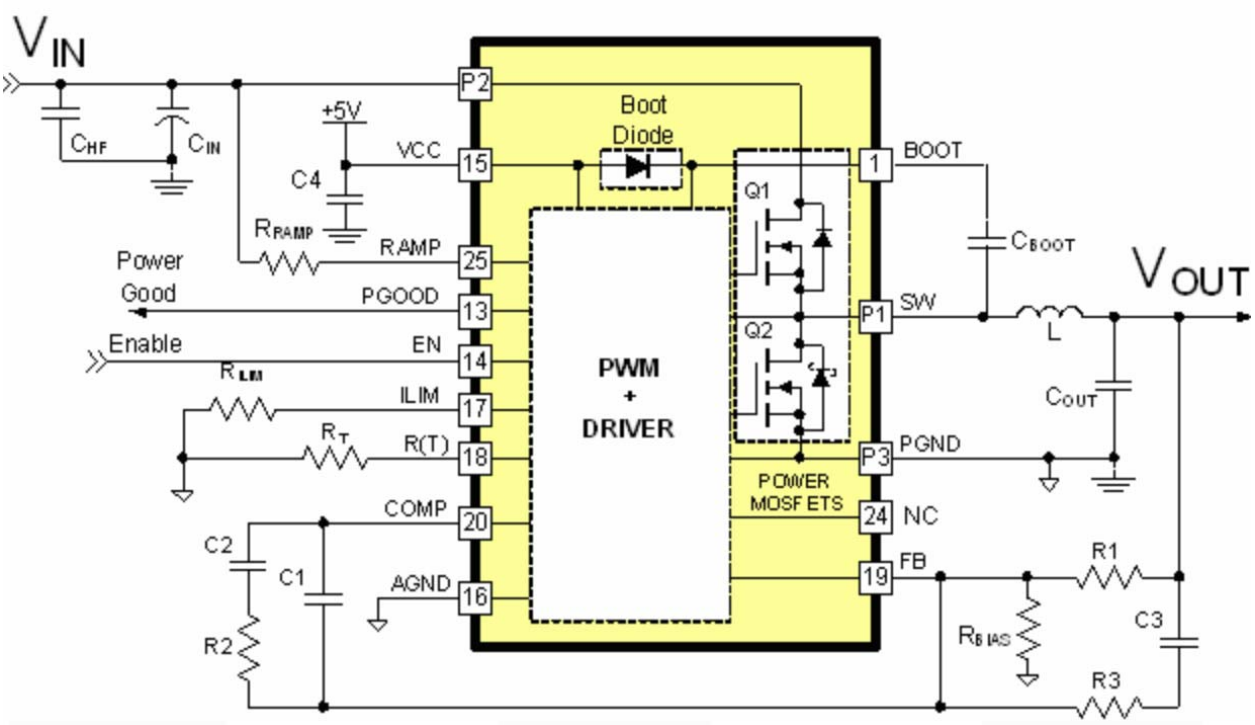


Figure 1. Typical Application

Block Diagram

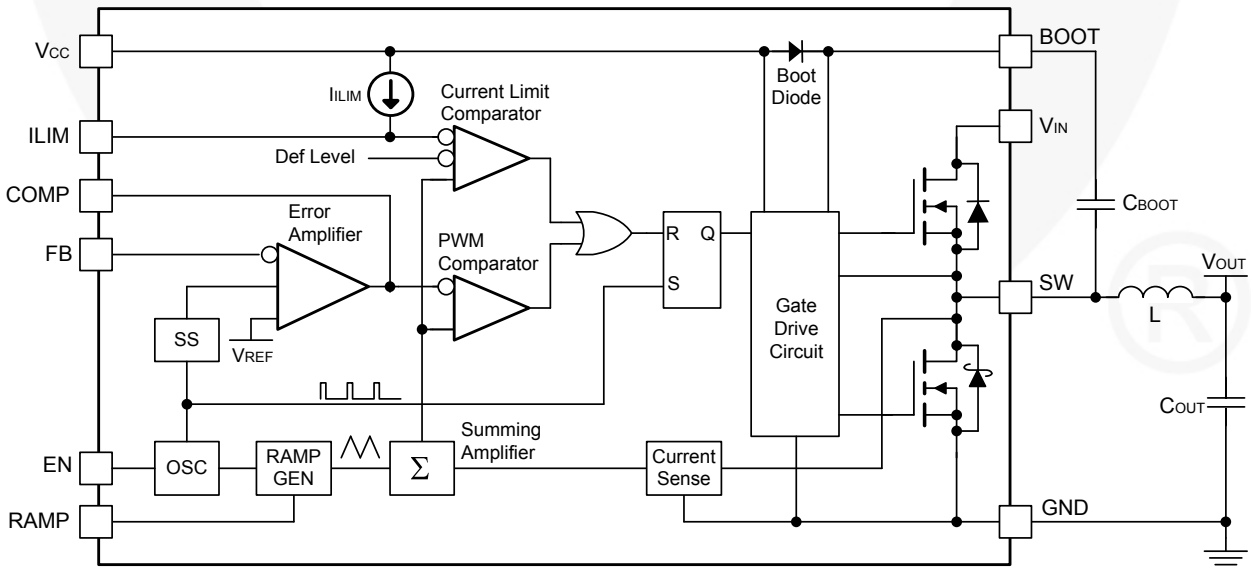


Figure 2. Block Diagram

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Pin Configuration

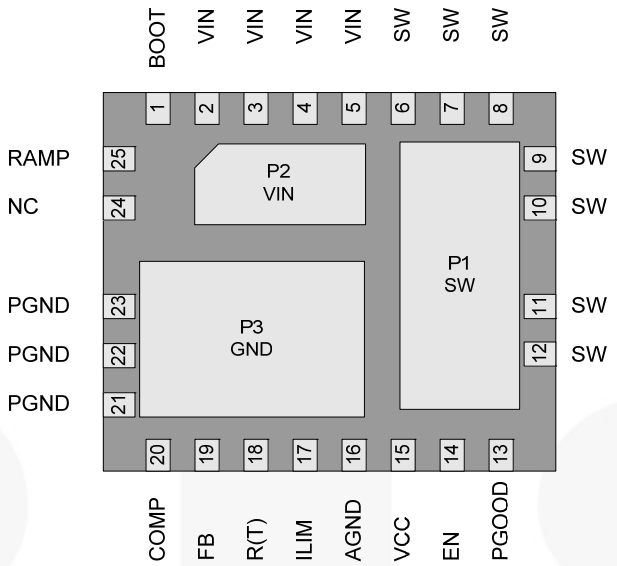


Figure 3. MLP 5x6 mm Pin Configuration (Bottom View)

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 when EN is HIGH. 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	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.

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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	Transient (t < 20 ns, f < 600 KHz)	-5	30	V
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	FAN2103M	-10		+85	°C
		FAN2103EM	-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.

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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 = 0.7 V, V_{CC} = 5 V, f_{SW} = 600 KHz		8	12	mA
	Shutdown: EN = 0, V_{CC} = 5 V		7	10	µA
V_{CC} UVLO Threshold	Rising V_{CC}	4.1	4.3	4.5	V
	Hysteresis		300		mV
Oscillator					
Frequency	R_T = 50 KΩ	255	300	345	KHz
	R_T = 24 KΩ	540	600	660	KHz
Minimum On-Time[2]			50	65	ns
Ramp Amplitude, pk–pk	16 V_{IN}, 1.8 V_{OUT}, R_T = 30 KΩ, R_{RAMP} = 200 KΩ		0.53		V
Minimum Off-Time[2]			100	150	ns
Reference					
Reference Voltage (V_{FB})	FAN2103M, 25°C	794	800	806	mV
	FAN2103EM, 25°C	795	800	805	mV
Temperature Coefficient	FAN2103M, -10 to +85°C		50		PPM
	FAN2103EM, -40 to +85°C		70		PPM
Error Amplifier					
DC Gain[2]	V_{CC} = 5 V	80	85		dB
Gain Bandwidth Product[2]		12	15		MHz
Output Voltage (V_{COMP})		0.4		3.2	V
Output Current, Sourcing	V_{CC} = 5 V, V_{COMP} = 2.2 V	1.5	2.2		mA
Output Current, Sinking	V_{CC} = 5 V, V_{COMP} = 1.2 V	0.8	1.2		mA
FB Bias Current	V_{FB} = 0.8 V, 25°C	-850	-650	-450	nA
Protection and Shutdown					
Current Limit	R_{ILIM} Open	3.8	5.0	7.0	A
I_{LIM} Current	25°C, V_{CC} = 5 V	9	10	11	µA
Over-Temperature Shutdown	Internal IC Temperature		+160		°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} ~500 mV)		250		mV
Soft-Start					
V_{OUT} to Regulation (T0.8)	Frequency = 600 KHz		5.3		ms
Fault Enable/SSOK (T1.0)			6.7		ms

Note:

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

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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
Control Functions					
EN Threshold, Rising			1.35	2.00	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 (Compared to V_{REF})	FB < V_{REF}	-14	-11	-8	%V_{REF}
	FB > V_{REF}	+7	+10	+13	%V_{REF}
PGOOD Output Low	$I_{OUT} \leq 2$ mA			0.4	V

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Typical Characteristics

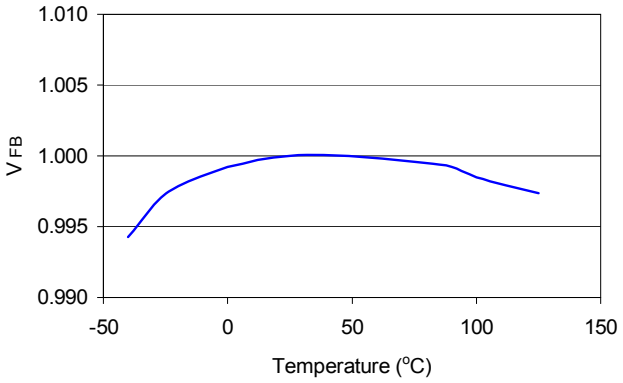


Figure 4. Reference Voltage (V_{FB}) vs. Temperature, Normalized

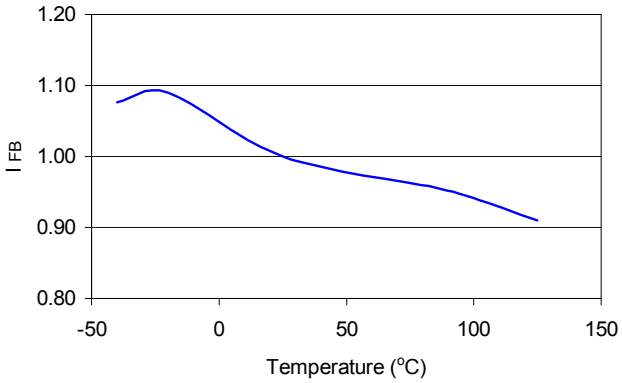


Figure 5. Reference Bias Current (I_{FB}) vs. Temperature, Normalized

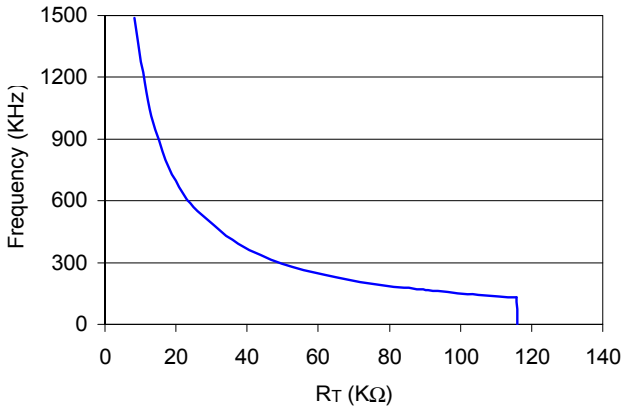


Figure 6. Frequency vs. R_T

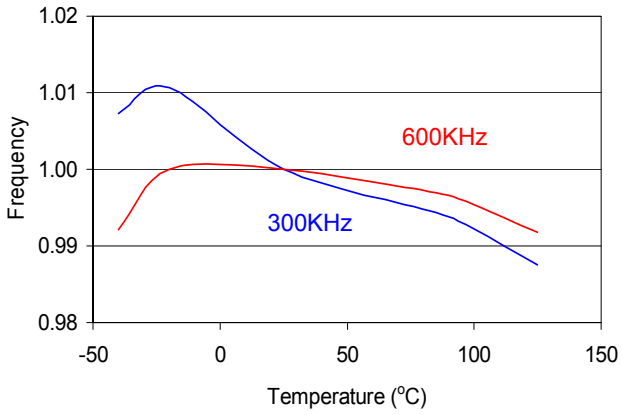


Figure 7. Frequency vs. Temperature, Normalized

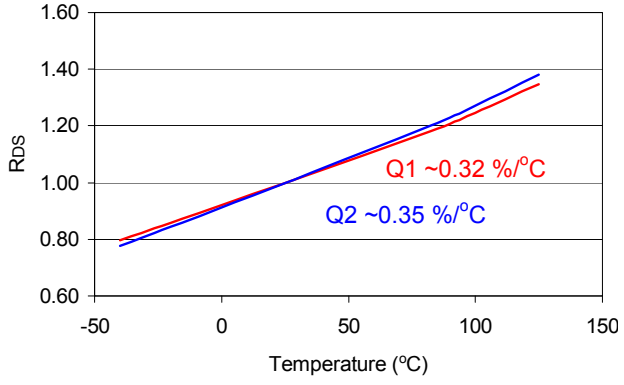


Figure 8. R_{DS} vs. Temperature, Normalized (V_{CC} = V_{GS} = 5 V)

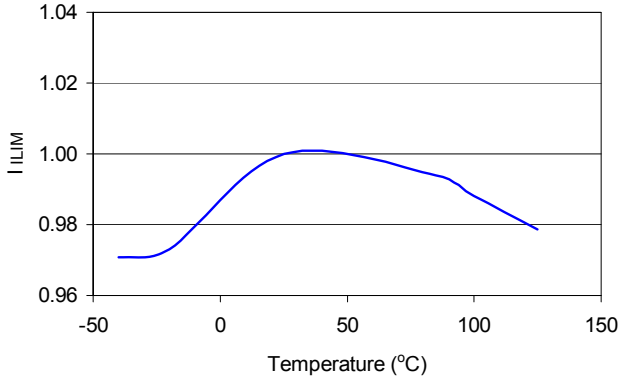


Figure 9. I_{LIM} Current (I_{ILIM}) vs. Temperature, Normalized

Application Circuit

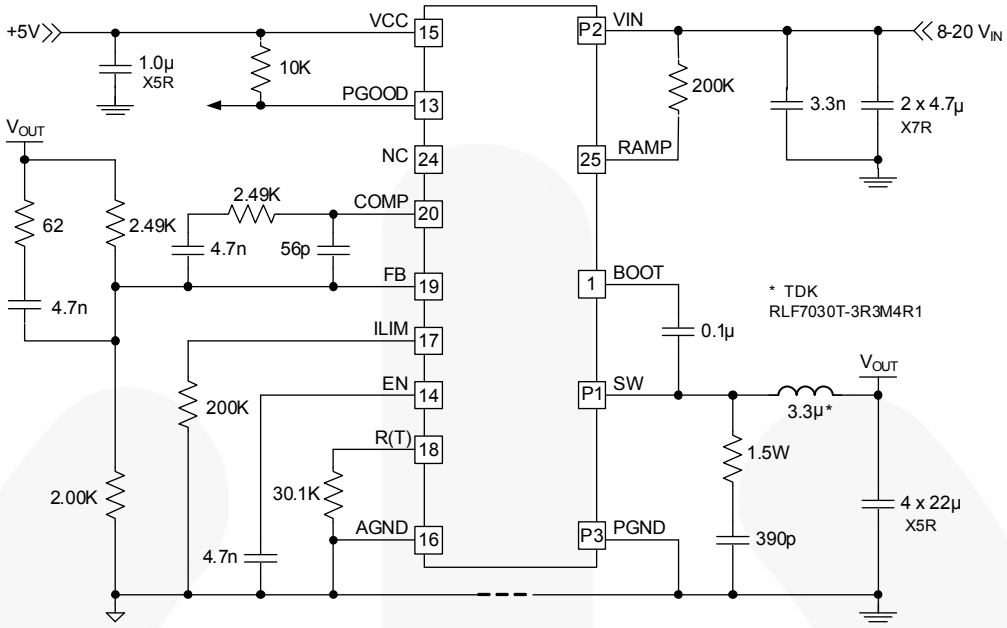


Figure 10. Application Circuit: 1.8 V_{OUT}, 500 KHz

Typical Performance Characteristics

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

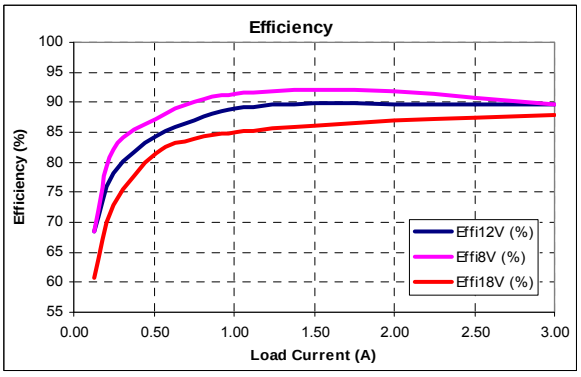


Figure 11. 1.8 V_{OUT} Efficiency Over V_{IN} vs. Load

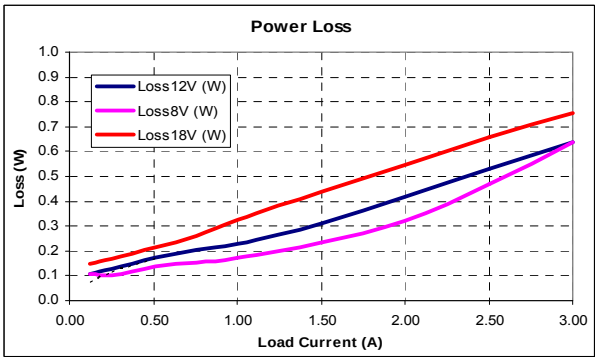


Figure 12. 1.8 V_{OUT} Dissipation Over V_{IN} vs. Load

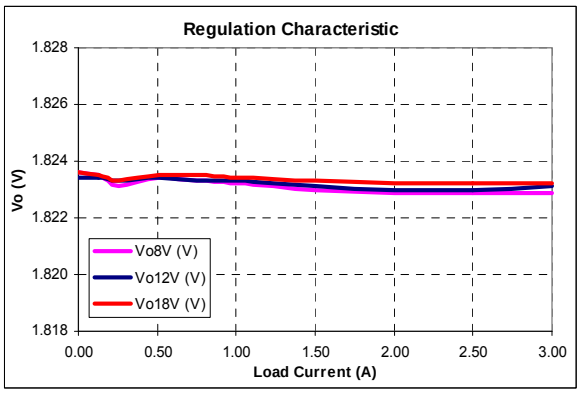


Figure 13. 1.8 V_{OUT} Regulation vs. Load

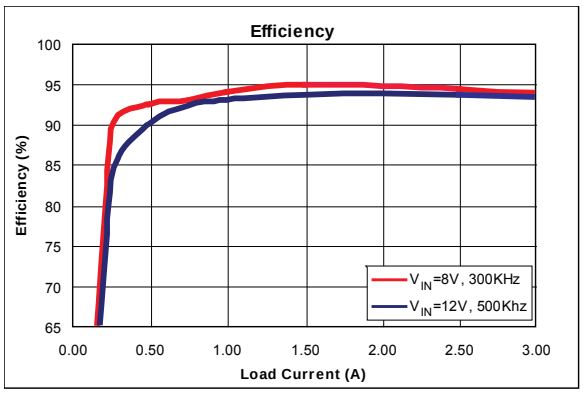


Figure 14. 3.3 V_{OUT} Efficiency vs. Load
(Circuit Values Changed)

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Typical Performance Characteristics (Continued)

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

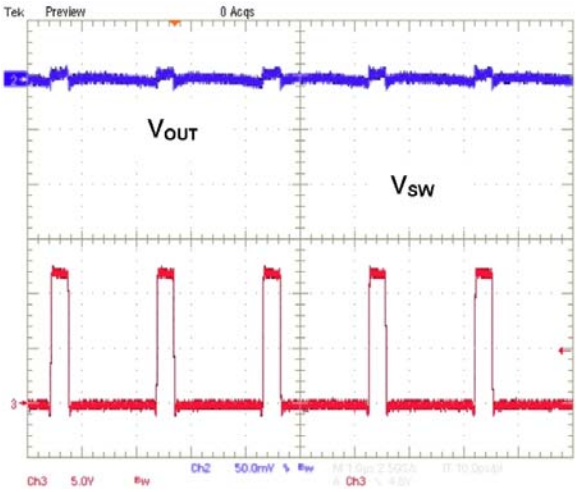


Figure 15. SW and V_{OUT} Ripple, 3 A Load

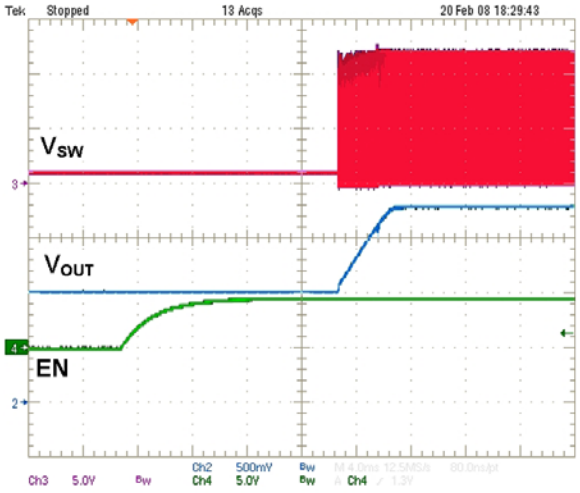


Figure 16. Startup with 1 V Pre-Bias on V_{OUT}

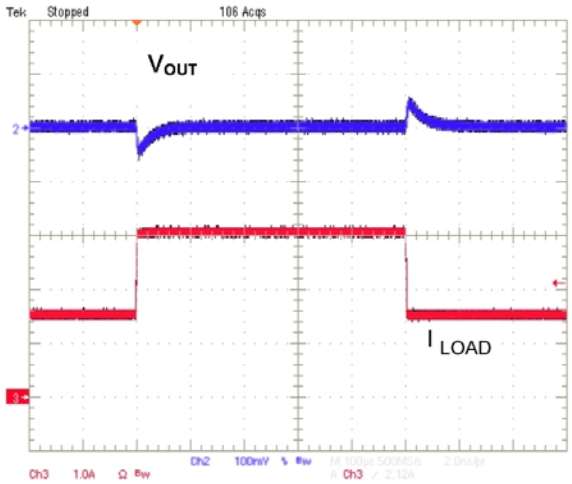


Figure 17. Transient Response, 1.5-3 A Load
(Circuit Values Changed)

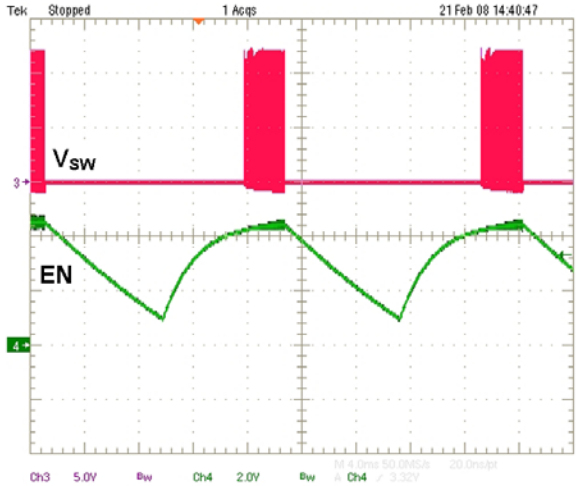


Figure 18. Re-start on Fault

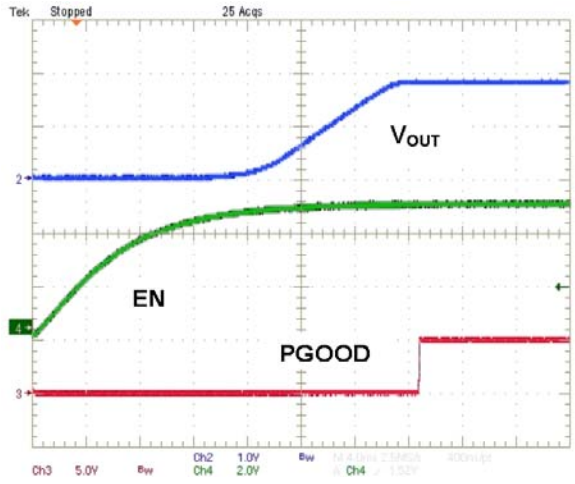


Figure 19. Startup, 3 A Load

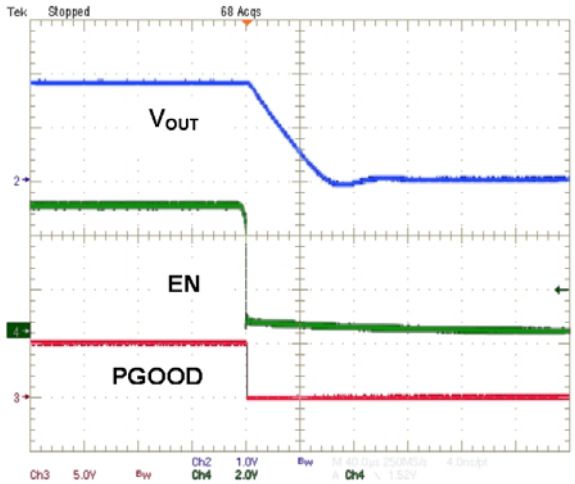


Figure 20. Shutdown, 3 A Load

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Circuit Description

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 (as shown in Figure 1), 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 internal SS ramp has charged to 0.8 V (T0.8), the output voltage is in regulation. Until SS ramp reaches 1.0 V (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.

Soft-start time is a function of oscillator frequency.

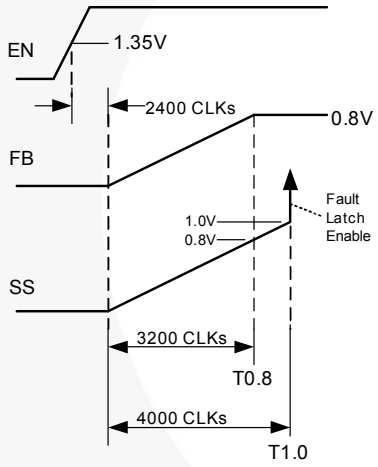


Figure 21. Soft-Start Timing Diagram

The regulator does not allow the low-side MOSFET to operate in full synchronous rectification mode until internal SS ramp reaches 95% of V_{REF} (~0.76 V). This helps the regulator start against pre-biased outputs (as shown in Figure 16) 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 FAN2103 requires a 5 V supply rail to bias the IC and provide gate-drive energy and controller power. Connect a ≥ 1.0 µf X5R or X7R decoupling capacitor between VCC and PGND. Whenever the EN pin is pulled up to V_{CC}, the 5 V supply connected to V_{CC} should be turned ON after V_{IN} comes up. If the power supply is turned ON using EN pin with an external control after V_{CC} and V_{IN} come up, the V_{CC} and V_{IN} power sequencing is not relevant.

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 0.8 V to ~80% of V_{IN} by an external resistor divider (R1 and R_{BIAS} in Figure 1).

The internal reference is 0.8 V with 650 nA, 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:

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

Connect R_{BIAS} between FB and AGND.

Setting the Frequency

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

$$f_{(KHz)} = \frac{10^6}{(65 \bullet R_T) + 135} \quad (3)$$

where R_T is expressed in KΩ.

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

where frequency (f) is expressed in KHz.

The regulator does not start if R_T is left open.

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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:

$$\Delta IL = \frac{V_{OUT} \bullet (1 - D)}{L \bullet f} \quad (5)$$

where f is the oscillator frequency and:

$$L = \frac{V_{OUT} \bullet (1 - D)}{\Delta IL \bullet f} \quad (6)$$

Setting the Ramp Resistor Value

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

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

where frequency (f) is expressed in KHz.

Setting the Current Limit

The current limit system involves two comparators. The MAX I_{LIMIT} comparator is used with a V_{ILIM} fixed-voltage reference and represents the maximum current limit allowable. This reference voltage is temperature compensated to reflect the R_{DSON} variation of the low-side MOSFET. The ADJUST I_{LIMIT} comparator is used where the current limit needs to be set lower than the V_{ILIM} fixed reference. The 10 µA current source does not track the R_{DSON} changes over temperature, so change is added into the equations for calculating the ADJUST I_{LIMIT} comparator reference voltage, as is shown below. Figure 22 shows a simplified schematic of the over-current system.

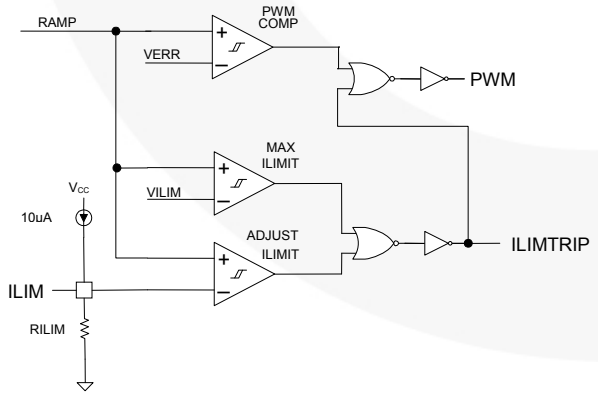


Figure 22. Current-Limit System Schematic

Since the I_{LIM} voltage is set by a 10 µA current source into the R_{ILIM} resistor, the basic equation for setting the reference voltage is:

$$V_{RILIM} = 10\mu A * R_{ILIM} \quad (8)$$

To calculate R_{ILIM}:

$$R_{ILIM} = V_{RILIM} / 10\mu A \quad (9)$$

The voltage V_{RILIM} is made up of two components, V_{BOT} (which relates to the current through the low-side MOSFET) and V_{RMPEAK} (which relates to the peak current through the inductor). Combining those two voltage terms results in:

$$R_{ILIM} = (V_{BOT} + V_{RMPEAK}) / 10\mu A \quad (10)$$

$$R_{ILIM} = \{0.96 + (I_{LOAD} * R_{DSON} * K_T * 8)\} + \{D*(V_{IN} - 1.8)/(f_{SW}*0.03*R_{RAMP})\}/10\mu A \quad (11)$$

where:

$V_{BOT} = 0.96 + (I_{LOAD} * R_{DSON} * K_T * 8)$;

$V_{RMPEAK} = D*(V_{IN} - 1.8)/(f_{SW}*0.03*R_{RAMP})$;

I_{LOAD} = the desired maximum load current;

R_{DSON} = the nominal R_{DSON} of the low-side MOSFET;

K_T = the normalized temperature coefficient for the low-side MOSFET (on datasheet graph);

$D = V_{OUT}/V_{IN}$ duty cycle;

f_{SW} = Clock frequency in kHz; and

R_{RAMP} = chosen ramp resistor value in kΩ.

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 23 shows a complete Type-3 compensation network. Type-2 compensation eliminates R3 and C3.

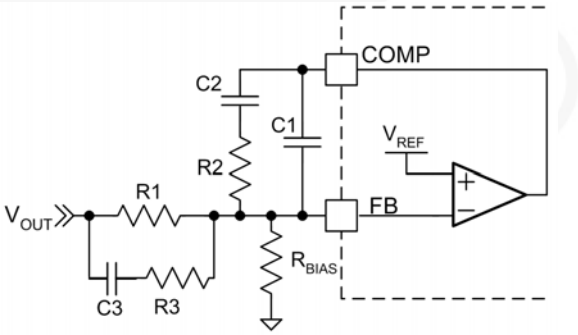


Figure 23. Compensation Network

Because the FAN2103 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.

R_{RAMP} provides feedforward compensation for changes in V_{IN}. With a fixed R_{RAMP} value, the modulator gain increases as V_{IN} is reduced, which could make it difficult to compensate the loop. For designs with low input voltages (3 V to 6.5 V), it is recommended that a separate R_{RAMP} and the compensation component values are used as compared to designs with V_{IN} between 6.5 V and 24 V.

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<0.25 V. The MOSFET is not turned on again unless FB>0.5 V. This behavior discharges the output without causing undershoot (negative output voltage).

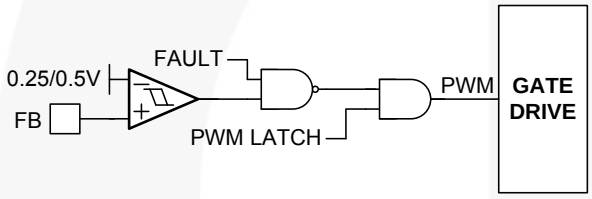


Figure 24. Latched Fault Response

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 ~0.7 V while the low-side MOSFET is fully enhanced. The fault latch is set immediately upon detection.

The two fault protection circuits above are active all the time, including during soft-start.

Auto-Restart

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

Depending on the external circuit, the FAN2103 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 (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)

With EN 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 1 µA current sink from discharging EN to 1.1 V.

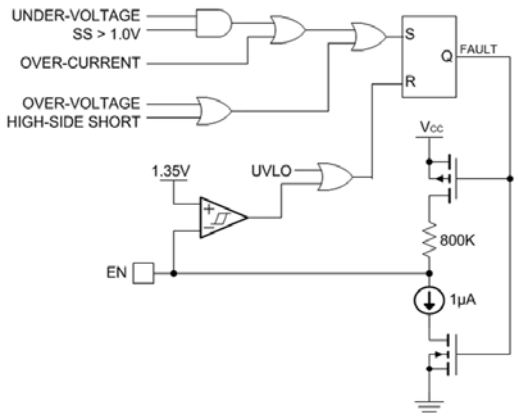


Figure 25. Fault Latch with Delayed Auto-Restart

Over-Temperature Protection

FAN2103 incorporates an over-temperature protection circuit that sets the fault latch when a die temperature of about 160°C is reached. The IC is allowed to restart when the die temperature falls below 130°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).

PCB Layout

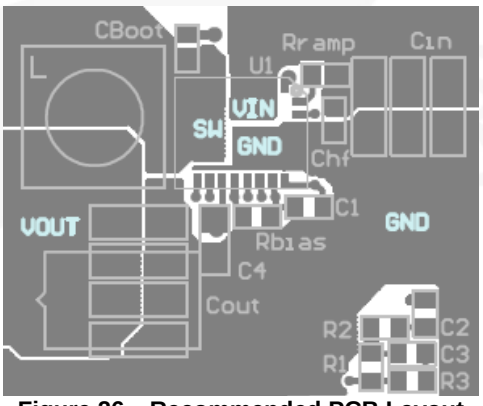


Figure 26. Recommended PCB Layout

Physical Dimensions

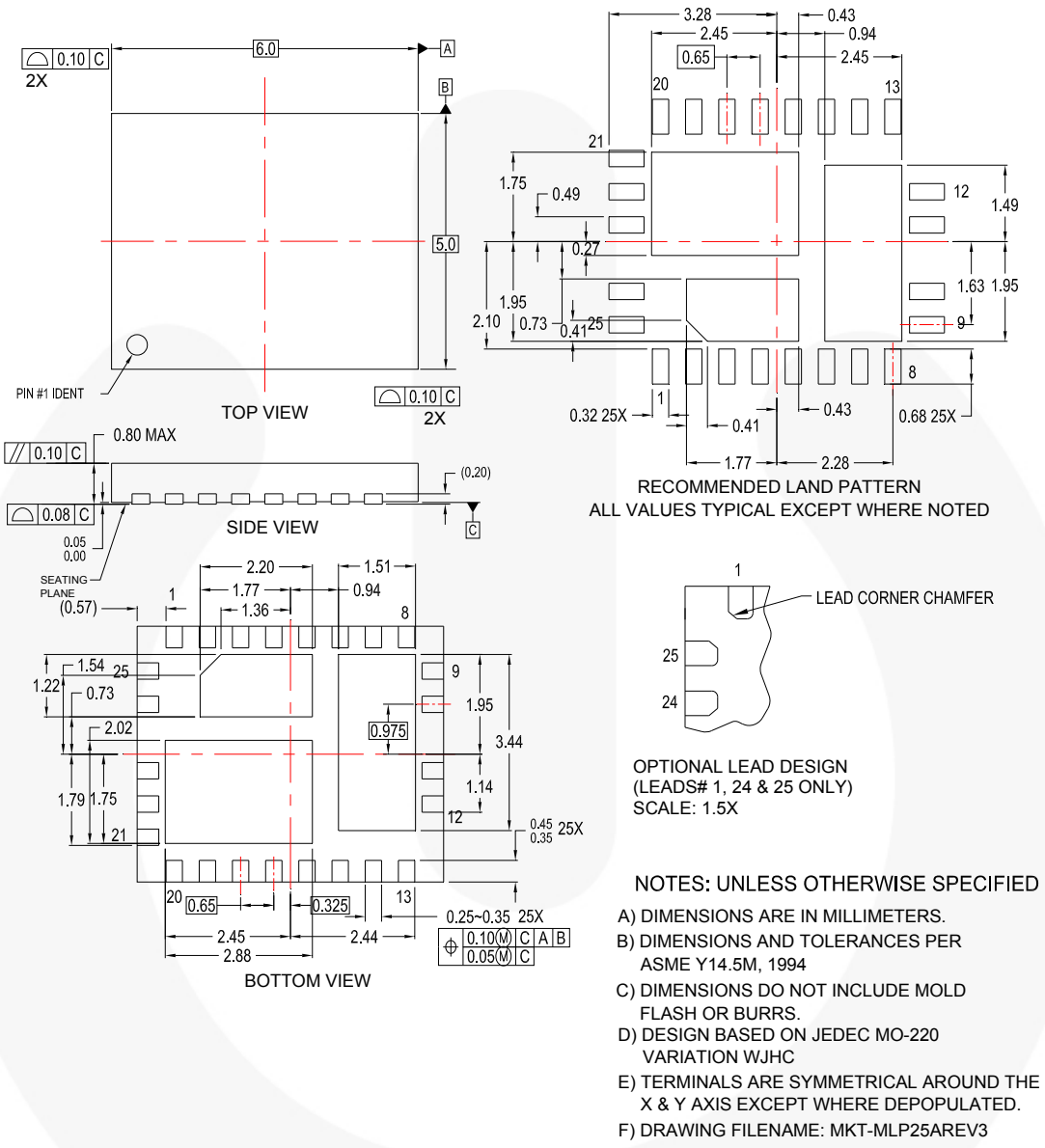


Figure 27. 5x6 mm Molded Leadless Package (MLP)

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