5V Input 4A 1.5MHz Synchronous Step-Down DC/DC Converter

❖ GENERAL DESCRIPTION

AX3704 can operate with input voltage from 2.5V to 5.5V and provide output range from 0.6V to input level, thanks to its 100% duty cycle operation. The constant on-time control scheme simplifies loop compensation and offers excellent load transient response.

AX3704 consumes extremely low 15μA quiescent current hence achieves superior light load efficiency. AX3704 is a 1.5MHz, 4A constant on-time (COT) controlled synchronous step-down converter. The high gain error amplifier in the control loop provides excellent load and line regulation. Proprietary adaptive on-time helps AX3704 to achieve nearly constant switching frequency across load range. AX3704 has cycle-by-cycle current limit and hiccup mode to protect over-load or short circuit fault conditions.

AX3704 is available in low profile 10 leads DFN 3mm x 3mm packages.

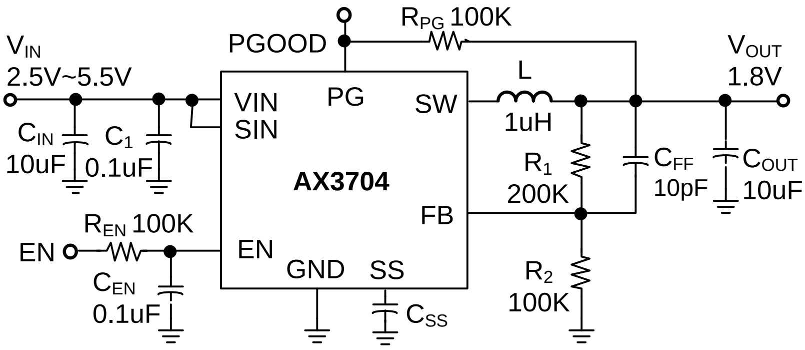
❖ FEATURES

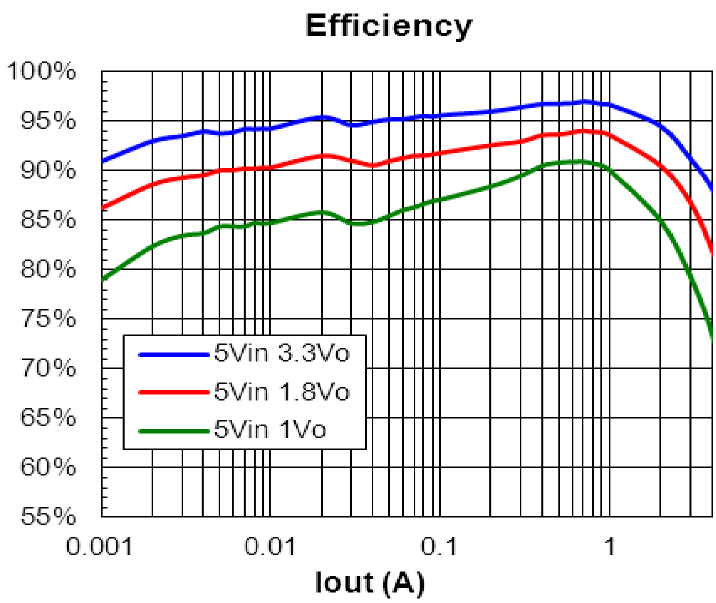
- +/- 2% 0.6V Feedback Voltage
- Up to 95% Efficiency
- Proprietary Fast Transient Constant On Time Architecture Stable with low ESR Ceramic Output Capacitors
- Wide Input Range from 2.5V to 6V
- 1.5MHz Switching Frequency
- 15μA Low Quiescent Current
- 4A Output Current
- 1.21V Accurate Enable Threshold
- Cycle-by-cycle Current Limit Protection
- 100% Duty Cycle Operation
- Built-in 80mΩ/50mΩ Power Switches
- Internal 1msec Soft-Start
- Over-Load and Short Circuit Hiccup Mode
- Open Drain Power Good Indication
- Output Discharge
- Thermal Shutdown Protection
- Available in Small DFN3X3_10L
- RoHS and Halogen free compliance.

❖ APPLICATION

- WiFi RF Moudules
- Solid-State and Hard Disk Drives
- Smart Phone and Tablets
- DC/DC Micro Modules

❖ TYPICAL APPLICATION

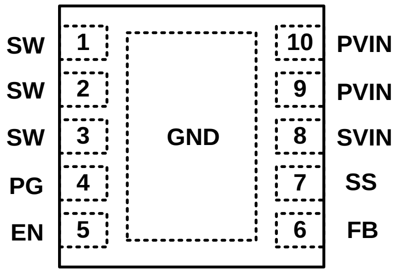




❖ PIN ASSIGNMENT

The package of AX3704 ; the pin assignment is given by:

Top View



EXPOSED PAD ON BACKSIDE

DFN3X3-10L

Name	Description
SW	Power Switch Node
PG	Power Good Open-drain Output. Connect a 100kΩ pull-up resistor to V_{IN} or V_{OUT}.
EN	Regulator Enable Control Input with accurate 1.21V enable threshold which can be used to build precision R-C turn-on delay and input under-voltage lockout. Don’t float this pin.This pin has an pull-down resistor of typically 1MΩ to GND. • Drive EN above 1.21V to turn on the converter • Drive EN below 1.11V to turn off the converter and discharge output
FB	Voltage Feedback Input. Connect a resistor divider between output and FB to program the output voltage. VFB is regulated to 0.6V.
SS	Soft-start programming pin, connect a capacitor from this pin to ground to program the soft-start time. As AX3704 also has internal 1ms soft-start, the actual soft-start time will be the longer one of the programmed value and the internal value. T_{SS}=Max(1ms,0.6V*Css/2uA)
SVIN	Signal Input Supply Voltage
PVIN	Power Input Supply Voltage
GND	Power ground

❖ ORDER/MARKING INFORMATION

Order Information	Top Marking
AX3704 XXX X Package Type: J10: DFN-10L Packing: Blank : Tube, A : Taping	3 7 0 4 → Part number Y Y W W X → ID code: internal WW: 01~52 Year: 18=2018, 19=2019, 20=2020, 21=2021, 22=2022 : 45=2045

❖ ABSOLUTE MAXIMUM RATINGS (Reference to GND) (Note1)

V_{IN} .... -0.3V to +6.5V
V_{SW} .... -0.3V to V_{IN} +0.3V
Dynamic V_{SW} in 10ns Duration.. -2V to V_{IN} +2V
The other Pins............ .... -0.3V to +6.5V

Junction Temperature Range .. -40°C to +150°C
Storage Temperature Range .. -65°C to +150°C
ESD .... Class 2
Lead Temperature(Soldering 10s) .... 260°C

Recommend Operating Conditions (Note2)
Input Voltage (V_{BAT}) ....+2.5V to 5.5V
Output Voltage (V_{OUT}) ....+0.6V to V_{IN}

Operating Temperature Range ..... -40°C to +85°C

Thermal information (Note3, 4)
Maximum Power Dissipation(T_A=25°C)
DFN3x3_10L 1.8W

Thermal Resistance(θ_{JA}) .... 56°C/W
Thermal Resistance(θ_{JC}) .... 8.3°C/W

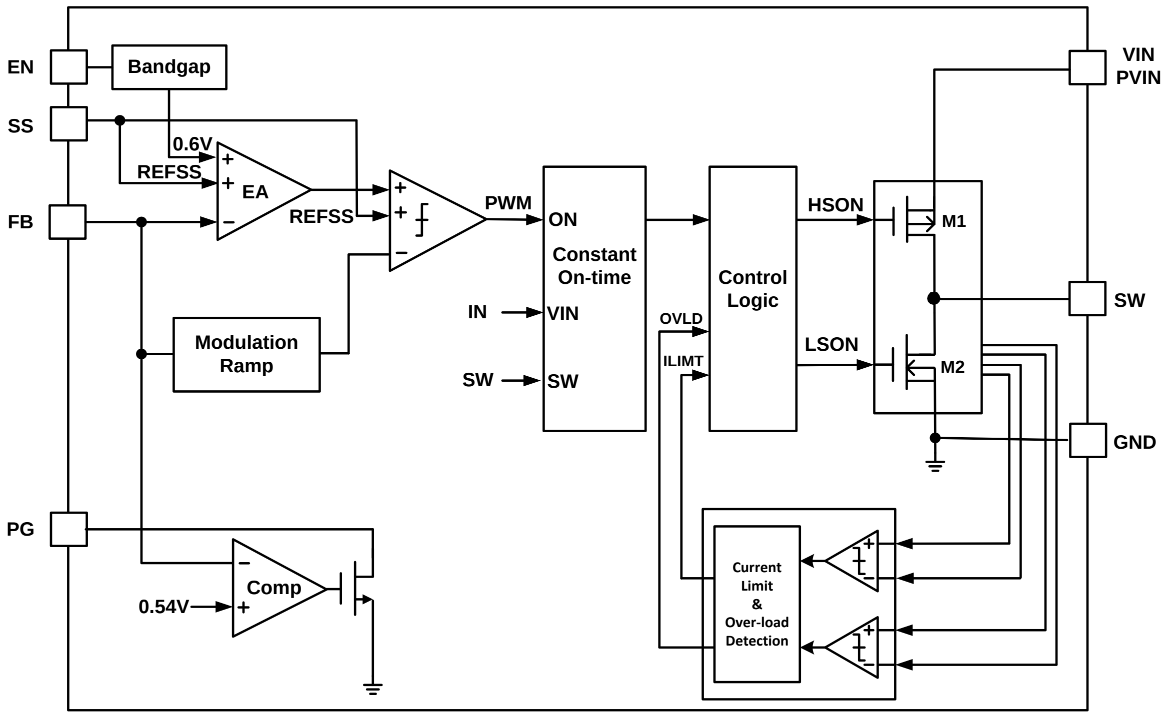
Note(1): Stress exceeding those listed “Absolute Maximum Ratings” may damage the device.
Note(2): The device is not guaranteed to function outside of the recommended operating conditions.
Note(3): Measured on JESD51-7, 4-Layer PCB.
Note(4): The maximum allowable power dissipation is a function of the maximum junction temperature T_{J_MAX}, the junction to ambient thermal resistance θ_{JA}, and the ambient temperature T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by $P_{D\_MAX}= (T_{J\_MAX}-T_A)/\theta_{JA}$. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.

❖ ELECTRICAL CHARACTERISTICS

TA =+25°C, VIN=5V, unless otherwise noted. Typical values are at VIN =VEN =5V and VOUT =1.8V.

Characteristics	Conditions	Min	Typ	Max	Units
Input Voltage Range V_{IN}		2.5		6.0	V
Shutdown Current	V_{EN} = 0V, V_{IN} = 5.5V		0.1	1	μA
Input Under Voltage Lockout Threshold	V_{IN} Increasing	2.3	2.4	2.5	V
Input Under Voltage Lockout Hysteresis			280		mV
Quiescent Current I_Q	V_{FB} = 0.63V		15	20	μA
Feedback Voltage V_{FB}		588	600	612	mV
Feedback Current I_{FB}		-50	1	+50	nA
HS Switch Current Limit			6.5		A
HS Main Switch On Resistance	V_{IN}=5V		80		mΩ
LS Synchronous Switch On Resistance	V_{IN}=5V		50		mΩ
Soft-start charging current			2		μA
HS Leakage Current	V_{IN} = 5.5V, V_{EN} = V_{SW} = 0V		0.1	2	μA
LS Leakage Current	V_{IN} = V_{SW} = 5.5V, V_{EN} = 0V		0.1	2	μA
PWM Switching Frequency	I_{IOUT} = 1A		1.5		MHz
PGOOD Output Low Voltage	V_{FB} =0.5V,sink 1mA		0.2	0.3	V
PGOOD Output Leakage Current	V_{FB} = 0.63V , VPGOOD = V_{IN} = 5.5V		0.01	0.2	μA
Input Voltage Range V_{IN}	V_{FB} ramp up from under voltage	-13	-10	-7	%
PGOOD Under Voltage Rise Threshold	V_{FB} ramp down from regulation		-15		%
PGOOD Under Voltage Fall Threshold	PGOOD going High to Low		30		μs
PGOOD Delay	V_{EN} ramp up	1.18	1.21	1.24	V
EN On Threshold	V_{EN} ramp down		1.11		
EN Off Threshold		700	1000	1300	kΩ
EN Internal Pull Down Resistor			150		Ω
Output Discharge Resistance			160		℃
Thermal Shutdown			30		℃
Thermal Shutdown Hysteresis	V_{FB} ramp up from under voltage	-13	-10	-7	%

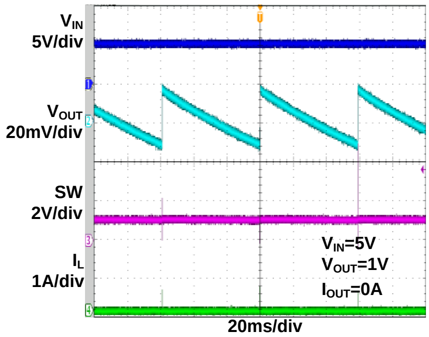
❖ Functional Block Diagram



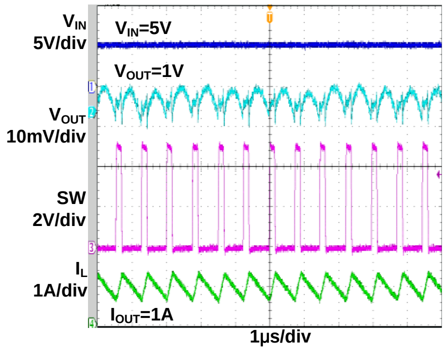
❖ TYPICAL PERFORMANCE CHARACTERISTICS

CIN=10uF, COUT=10uF, L=1uH, TA=+25℃

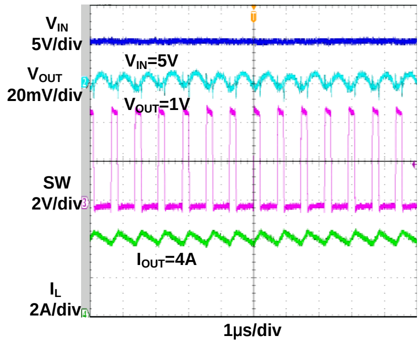
Steady State Test



Steady State Test



Steady State Test



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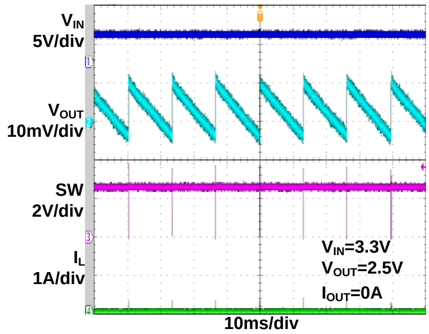

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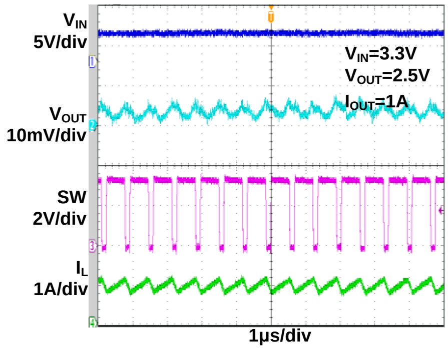

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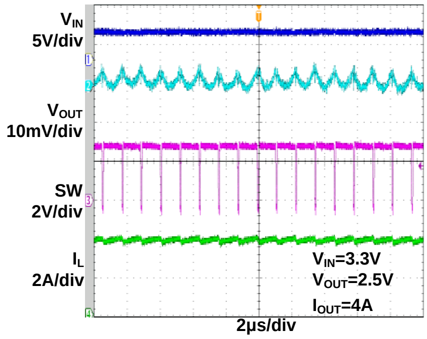
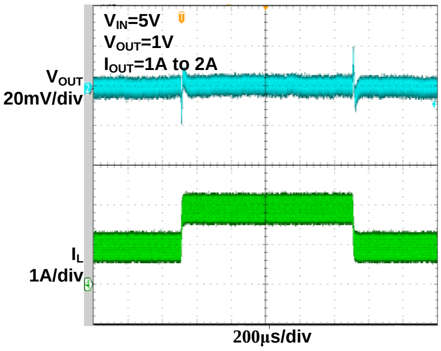


Load Transient Response



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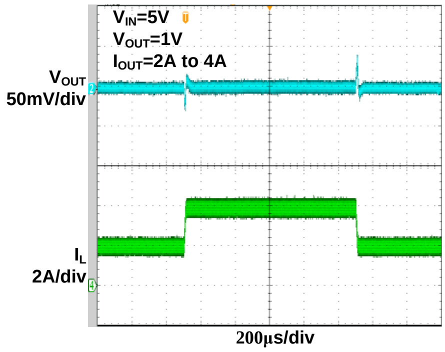

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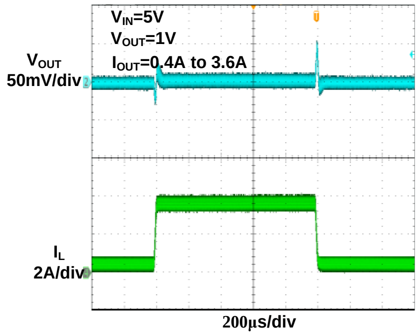
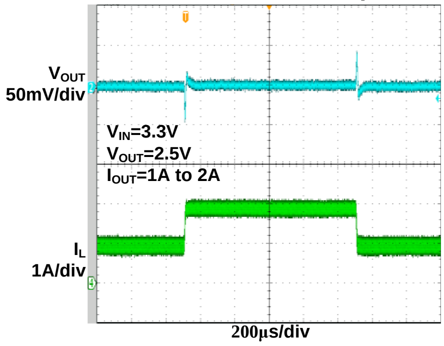


C_{IN}=10uF, C_{OUT}=10uF, L=1uH, T_A=+25℃

Load Transient Response



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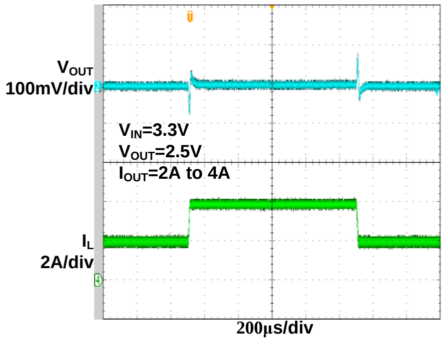
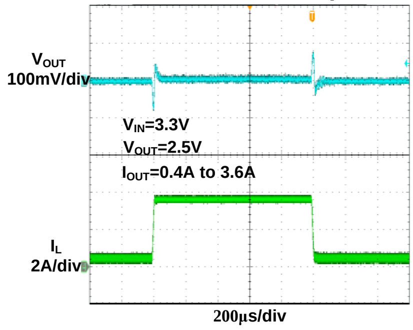
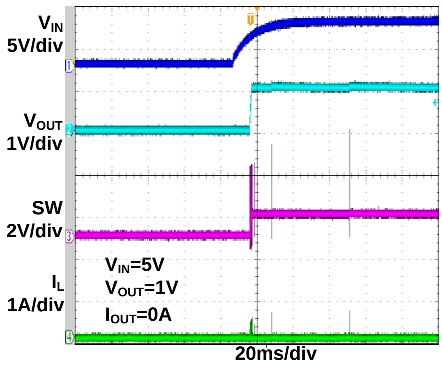


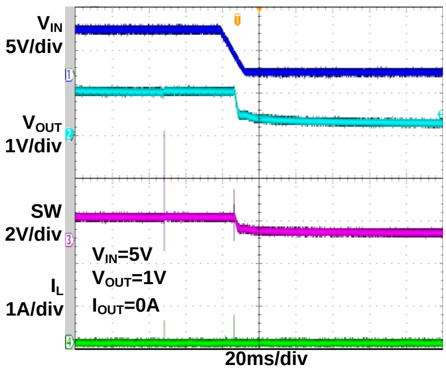
Load Transient Response



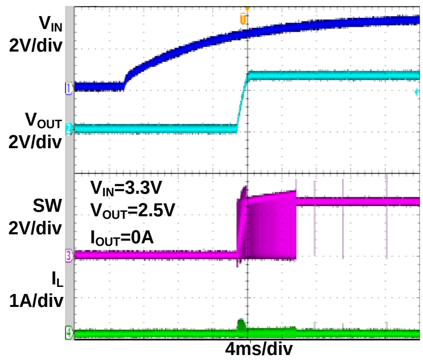
Vin Power On



Vin Power Off



Vin Power On



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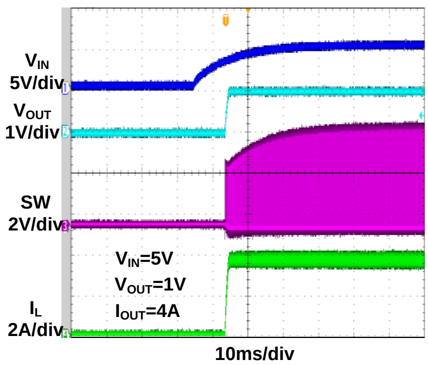

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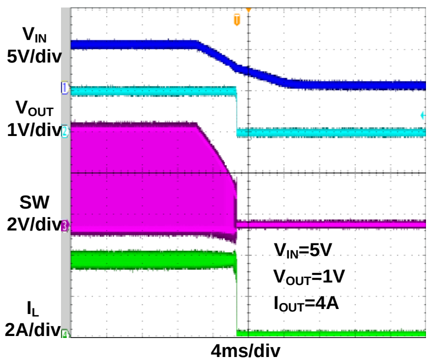

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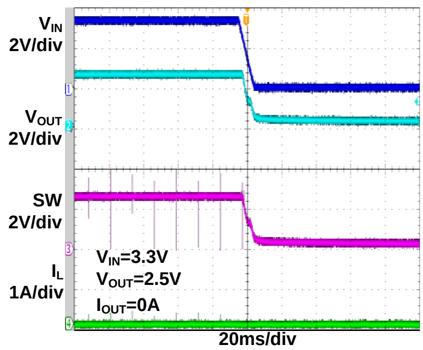
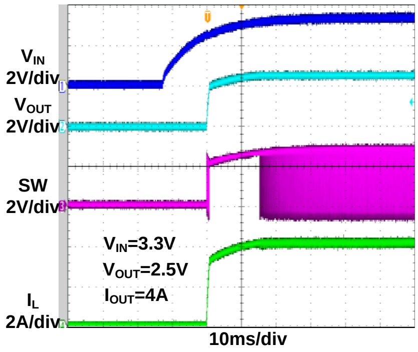
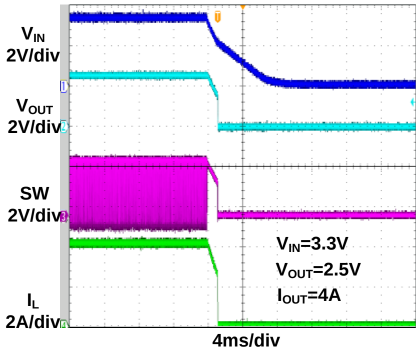


CIN=10uF, COUT=10uF, L=1uH, TA=+25℃

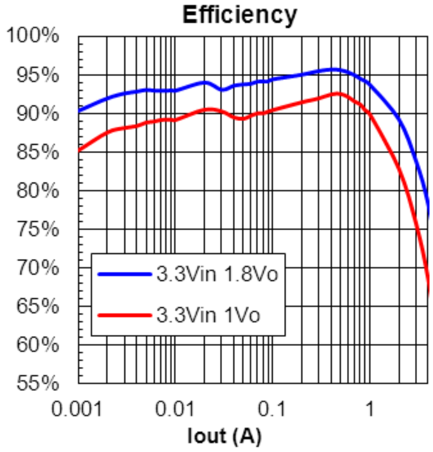
Vin Power On



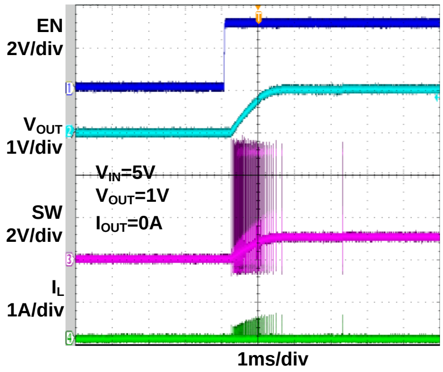
Vin Power Off



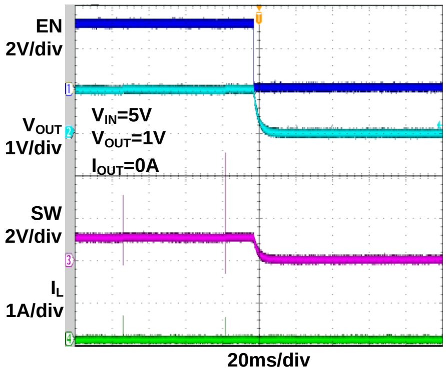
Efficiency



EN On



EN Off



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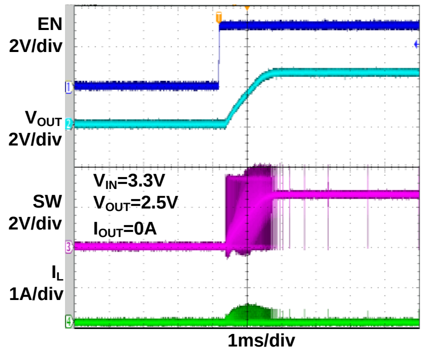

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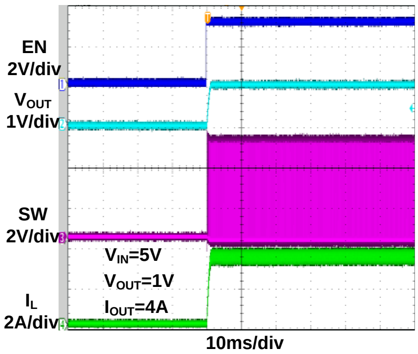

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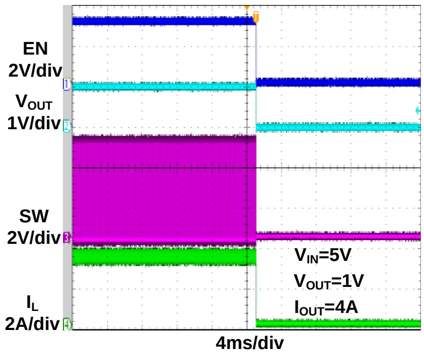

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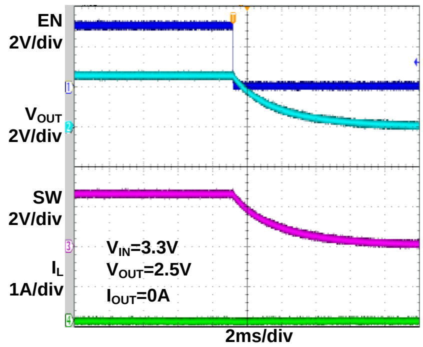
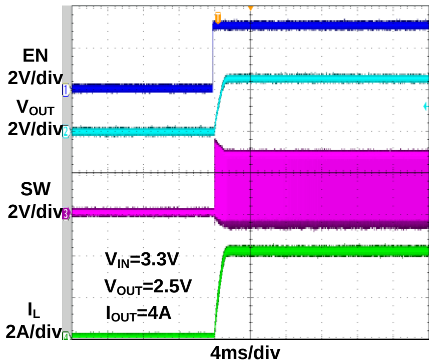


CIN=10uF, COUT=10uF, L=1uH, TA=+25℃

EN On



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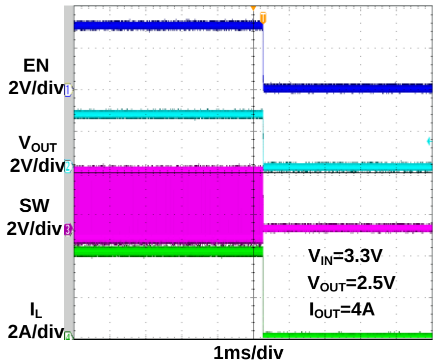
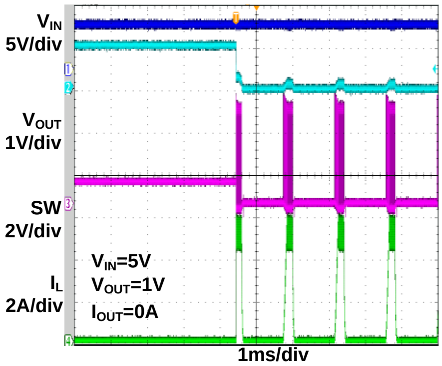
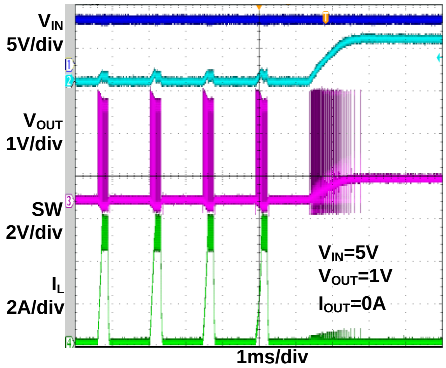


Short Circuit Entry



Short Circuit Entry



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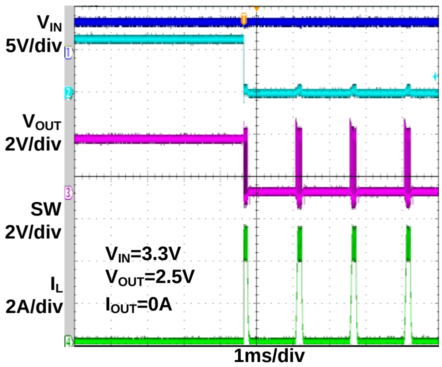
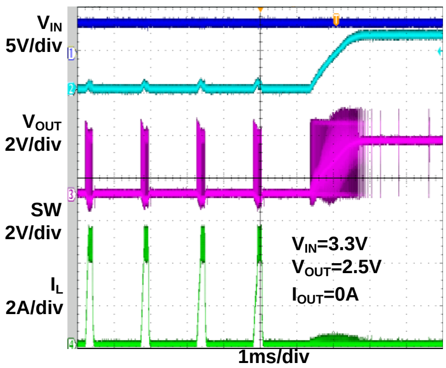


Short Circuit Entry



Enable
When input voltage is above the under voltage lock-out threshold, AX3704 can be enabled by pulling the EN pin to above 1.21V. AX3704 is disabled if the EN pin is pulled below 1.11V. The enable/disable threshold for EN pin is accurately designed to be 1.21V and 1.11V respectively, so one can also use external resistor divider to program the desired input under-voltage lockout level.

Light Load Operation
In light load condition where the converter operates in discontinuous mode, AX3704 cuts down its quiescent current to as low as 15uA and achieves excellent light load efficiency.

Theory of Operation
AX3704 is a constant on-time control synchronous step-down converter that offers excellent transient response over a wide range of input voltage. It achieves superior light-load efficiency with extremely low quiescent current.

Constant On-time Control
Constant on-time control step-down converters turn on HS immediately when FB droops below reference. The HS is turned on for a pre-determined period (on-time) of time to ramp up the inductor current, and then the LS will be turned on to ramp down the inductor current. The cycle repeats itself if FB droops below reference again. AX3704 uses proprietary technique to take into account the load current impact and adjusts the on-time accordingly to achieve a constant switching frequency over entire load current range.
For AX3704, the on-time is approximately:

$$T_{ON} = \frac{V_{OUT}}{V_{IN}} \cdot 0.66\mu$$

Due to its immediate response on FB voltage droop and simplified loop compensation, constant on-time offers a superior transient response compare to traditional fixed frequency PWM control step-down converters.

Soft Start
AX3704 has built-in soft start of 1msec as well as external programmable soft-start. Connect a capacitor to SS pin to program desired soft-start time. AX3704 provides a constant charging current of 2uA from the SS pin. External soft-start time can be programmed as:

$$T_{EXT\_SS} = \frac{0.6V \cdot C_{SS}}{2\mu A}, \qquad T_{SS} = Max(1ms, \frac{0.6V \cdot C_{SS}}{2\mu A})$$

The actual soft-start time is the longer one of the programmed value and the internal value.

During the soft start period, output voltage is ramped up linearly to the regulation voltage, independent of the load current level and output capacitor value.

Current Limit and Hiccup Mode
AX3704 has cycle-by-cycle HS current limit protection to prevent inductor current from running away. Once HS current limit is triggered, AX3704 will turn on LS and wait for the inductor to drop down to a pre-determined level before the HS can be turned on again. If this current limit condition is repeated for a sustained long period of time, AX3704 will consider it over-load or short circuit. Either way, AX3704 will enter hiccup mode, where it stop switching for a pre-determined period of time before automatically re-try to start up again. It always starts up with soft-start to limit inrush current and avoid output overshoot.

Power Good Indication

AX3704 has open drain Power GOOD indicator PGOOD pin. When PGOOD is connected with external pull up resistor, it will be pulled up if output voltage is higher than 90% of regulation, otherwise PGOOD is pulled down by the internal open drain NMOS.

Application Information

Setting the Output Voltage

External feedback resistors are used to set the output voltage. Refer to typical application circuit on page1, the top feedback resistor R1 has some impact on the loop stability, so its recommended range is between 100kΩ-300kΩ. For any chosen R1, the bottom feedback resistor R2 can be calculated as:

$$R_2 = \frac{R_1}{\frac{V_{OUT}}{0.6} - 1}$$

Inductor Selection

The recommended inductor value for AX3704 is between 0.33uH to 1uH. Usually the inductor value is chosen to satisfy a desired ripple current:

$$L = \frac{V_{OUT} \cdot (V_{IN} - V_{OUT})}{V_{IN} \cdot f_{SW} \cdot \Delta I}$$

where ΔI is the inductor ripple current.
With the chosen ΔI, the peak inductor current will be:

$$I_{PK} = I_{LOAD} + \frac{1}{2} \cdot \Delta I$$

Input Bypass Capacitor Selection

The input current to the step-down converter is discontinuous with very sharp edges, therefore an input bypass capacitor is required. For best performance, it's recommended to use low ESR ceramic capacitors and place them as closeto the input pin as possible. For lowest temperature variations, use X5R or X7R dielectric ceramic capacitors.
The RMS current of the input capacitor is approximately:

$$I_{CIN\_RMS} = I_{OUT}\sqrt{D(1 - D)}$$

From the equation, it can be seen that the highest RMS current occurs when D is 0.5:

$$I_{CIN\_RMS} = \frac{1}{2} I_{OUT}$$

Choose the capacitor with RMS current rating higher than 1/2 I_{OUT}
The power dissipation on the input capacitor can be estimated with the RMS current and the ESR resistor.
Electrolytic or tantalum capacitors can also be used, but due to their significantly higher ESR, a small size ceramic capacitor should be placed as close to the IC as possible.
The voltage ripple on the input capacitor, neglecting the ESR impact, can be calculated as:

$$\Delta V_{CIN} = \frac{I_{LOAD}}{f_{SW} \cdot C_{IN}} \cdot \frac{V_{OUT}}{V_{IN}} \cdot \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Output Capacitor Selection

An output capacitor is required to obtain a stable output voltage. To minimize the output voltage ripple, ceramic capacitors should be used, and the ripple voltage can be estimated as:

$$\Delta V_{OUT} = \frac{1}{8} \cdot (1 - \frac{V_{OUT}}{V_{IN}}) \cdot \frac{V_{OUT}}{L} \cdot \frac{1}{(f_{SW})^2 \cdot C_{OUT}}$$

If electrolytic or tantalum capacitors are used, the ESR will dominate the output voltage ripple:

$$\Delta V_{OUT} = (1 - \frac{V_{OUT}}{V_{IN}}) \cdot \frac{V_{OUT}}{f_{SW} \cdot L} \cdot R_{ESR}$$

PCB Layout Recommendation

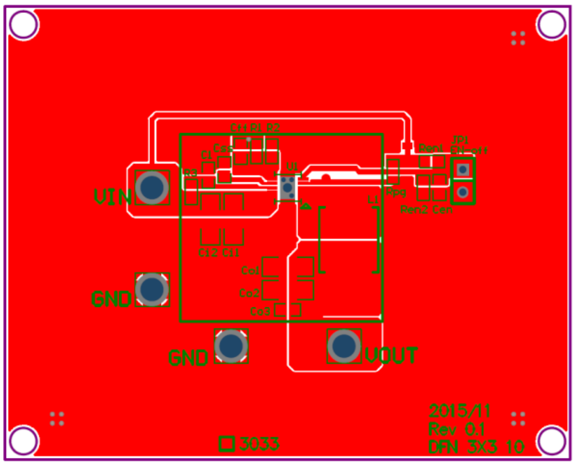
The physical design of the PCB is the final stage in the design of power converter. If designed improperly, the PCB could radiate excessive EMI and contribute instability to the power converter. Therefore, following the PCB layout guidelines below can ensure better performance of AX3704.

(1). The loop (Vin-SW-L-Cout-GND) indicates a high current path. The traces within the loop should be kept as wide and short as possible to reduce parasitic inductance and high-frequency loop area. It is also good for efficiency improvement.

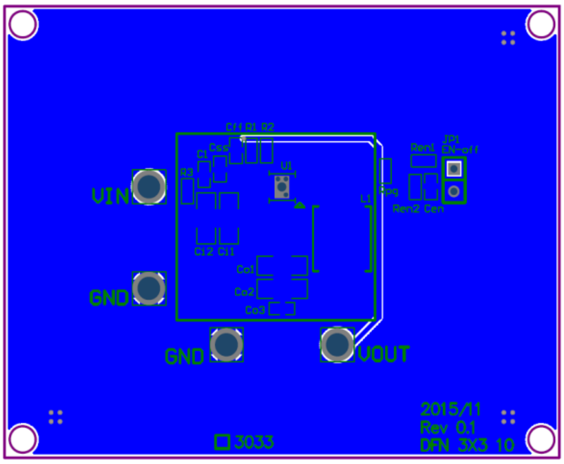
(2). Input capacitor as close as possible to the IC Pins (Vin and GND) and the input loop area should be as small as possible to reduce parasitic inductance, input voltage spike and noise emission.

(3). Feedback components (R_1, R_2 and C_{FF}) should be routed as far away from the inductor and the SW Pin as possible to minimize noise and EMI issue.

DFN3x3-10L

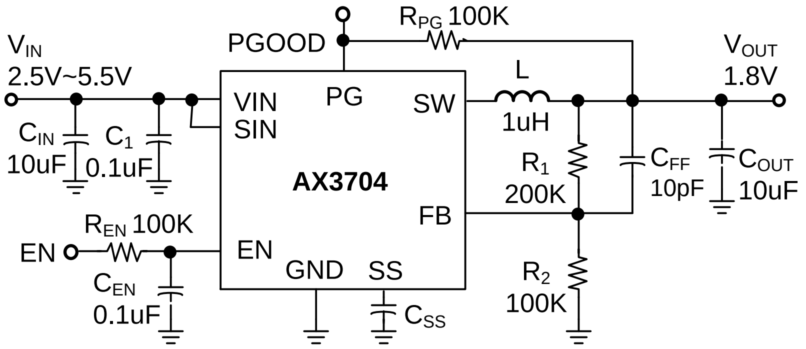


Top Layer



Bottom Layer

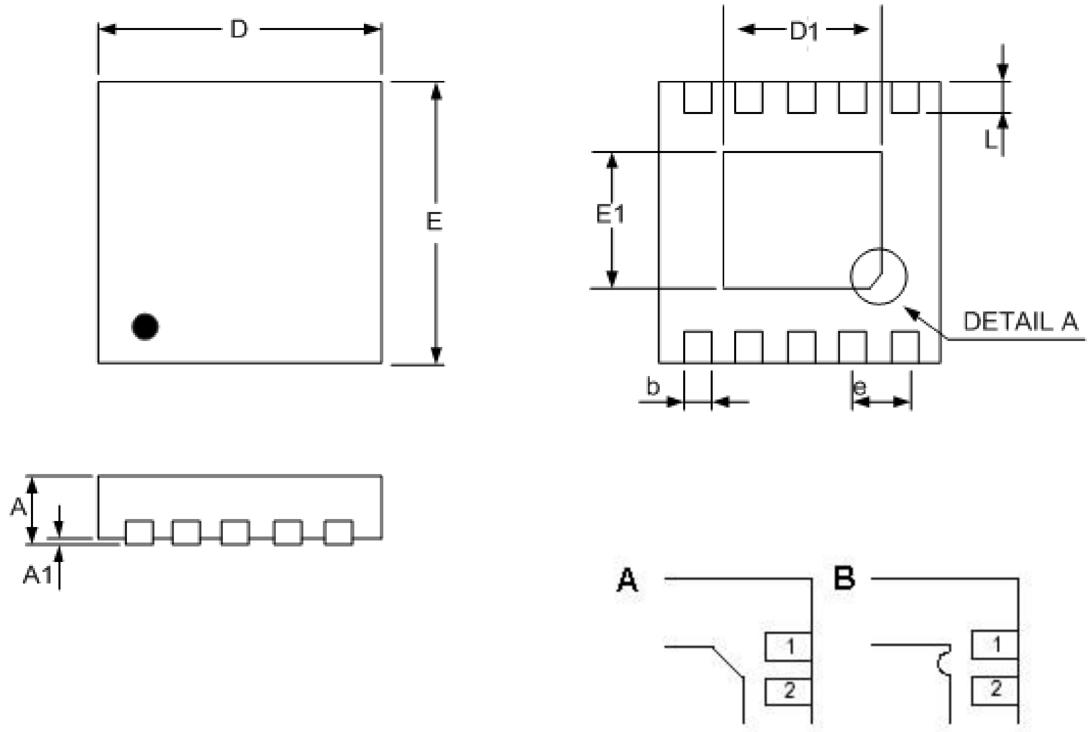
❖ AX3704 Application Schematic



EVB BOM List

Qty	Ref	Value		Description	Package
1	C_{IN}	10μF		Ceramic Capacitor, 10V, X5R	0805
1	C_{OUT}	10μF		Ceramic Capacitor, 10V, X5R	0805
2	C1, C_{EN}	0.1μF		Ceramic Capacitor, 10V, X5R	0603
1	C_{FF}	10pF		Ceramic Capacitor, 10V, X5R	0603
0	C_{SS}	NA		Ceramic Capacitor, 10V, X5R	0603
1	L	0.47uH~1uH		Inductor, MHCI06030-1R0M-R8AEI, 7.4mΩ, 15A	SMD
1	R1	Vout=3.3V	200KΩ	Resistor, ±1%	0603
		Vout=2.5V	240KΩ		
		Vout=1.8V	200KΩ		
		Vout=1.2V	200KΩ		
		Vout=1.0V	100KΩ		
1	R2	Vout=3.3V	43KΩ	Resistor, ±1%	0603
		Vout=2.5V	75KΩ		
		Vout=1.8V	100KΩ		
		Vout=1.2V	200KΩ		
		Vout=1.0V	150KΩ		
2	R_{PG}, R_{EN}	100KΩ		Resistor, ±1%	0603
1	Power IC	AX3704		Step-Down DC/DC Converter	DFN3X3-10L

❖ PACKAGE OUTLINES



DETAIL A

Thermal Pad Option

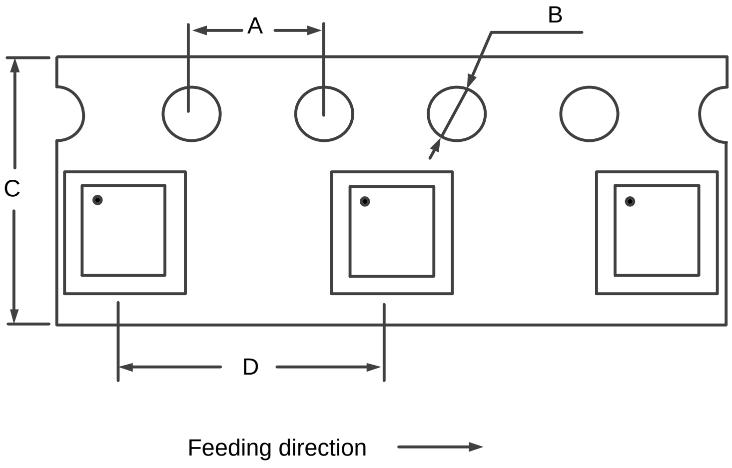
DFN3x3_10L Outline Dimensions, Unit: inches/mm

SYMBOLS	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	0.70	0.80	0.028	0.031
A1	0.00	0.05	0.000	0.002
b	0.18	0.30	0.007	0.012
D	2.90	3.10	0.114	0.122
D1	2.10	2.60	0.083	0.102
E	2.90	3.10	0.114	0.122
E1	1.35	1.75	0.053	0.069
e	0.50		0.020	
L	0.30	0.50	0.012	0.020

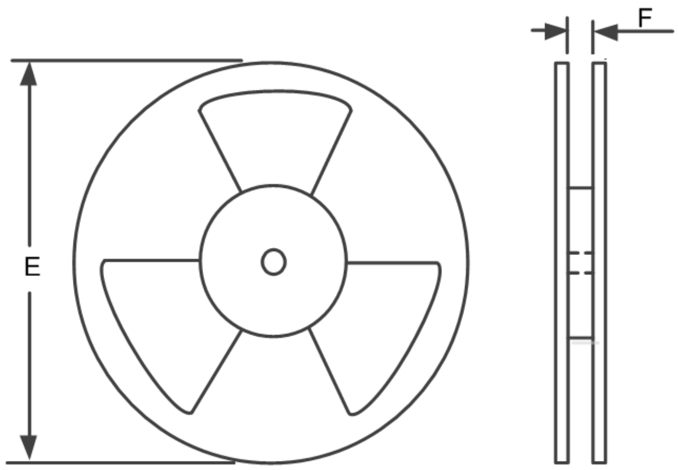
❖ CARRIER TAPE DIMENSION

DFN3x3-10L

1. Orientation / Carrier Tape Information :



1. Rokreel Information :



2. Dimension Details :

PKG Type	A	B	C	D	E	F	Q'ty/Reel
DFN3x3_10L	4.0 mm	1.5 mm	12.0 mm	8.0 mm	13 inches	13.0 mm	5,000