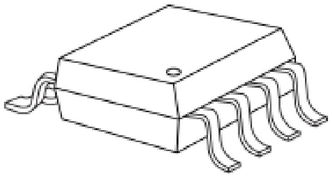
3A Synchronous Buck Regulator

IK5302

Description

The IK5302 is a 18V 3A synchronous step-down (buck) converter with two integrated High side and Low side N-LDMOS transistors. The IK5302 implements current control method which provides high stability during operation and fast response during abrupt load change. It operates from a 4.5V to 18V input voltage range and supplies up to 3A of load current. The IK5302 operates on fixed 1Mhz frequency.

Small Outline Package



SOP8

ORDERING INFORMATION

Device	Temperature Range	Package	Packing
IK5302DT	T_J= - 40 ... + 125 °C	SOP-8	Tape& Reel

Features

- 4.5V to 18V operating input voltage range
- Synchronous rectification: 120mΩ internal high-side switch and 80mΩ Internal low-side switch
- High efficiency up to 93%
- Output voltage adjustable to 0.8V
- 3A continuous output current
- Fixed 1MHz operation
- Cycle-by-cycle current limit
- Short-circuit protection and Thermal shutdown

Application

- Point of load DC/DC conversion
- PCIe graphics cards
- Set top boxes
- DVD drives and HDD
- LCD panels
- Cable modems
- Telecom/networking

Absolute Maximum Ratings

Parameter	Value	Unit
V_{in} to GND range	-0.3 to +20	V
LX to GND range	-0.3 to +20	V
FB, COMP , Vcc to GND range	-0.3 to +6	V
EN to GND range	-0.3 to +20	V
BS to LX	-0.3 to +6	V
Junction temperature range	-40 to +125	^{O}C
Storage temperature range	-55 to +150	^{O}C
ESD rating, HBM	2	kV
ESD rating, MM	200	V

* Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied.
Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

Thermal Resistance

Package	θ_{JA}	θ_{JC}	Unit
SOP-8	50	12	ºC/W

Typical Application Circuit

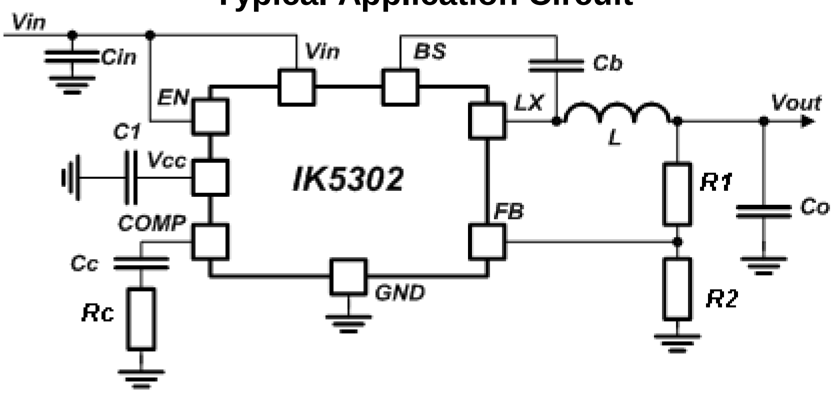
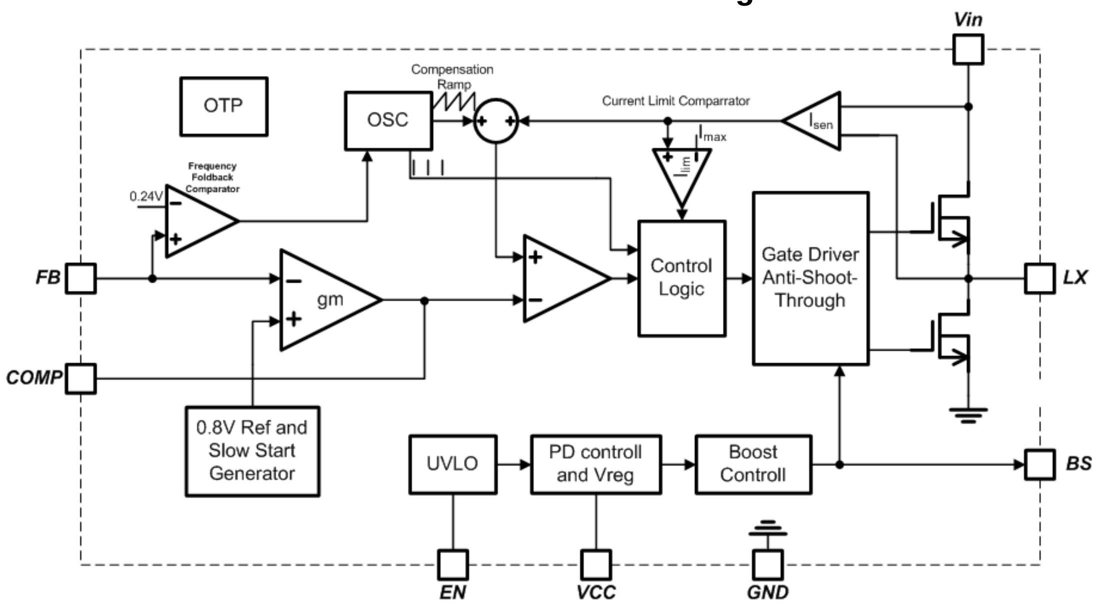


Figure 1.

Internal Block Diagram



Pin Description

Pin #	Pin Name	Pin Description
1	GND	Reference and internal controller and analogue part ground
2	Vin	Input supply voltage. When Vin rises above UVLO threshold IC starts to operate.
3	EN	Enable pin. Active level is High. Do not leave it open. Connect to Vin for normal operation or to GND for Disable case.
4	FB	Error amplifier feedback input. The FB pin via resistive divider between Vout and GND defines output voltage.
5	COMP	External loop compensation.
6	VCC	Internally generated supply voltage for internal control schematic. Normally ceramic capacitor with ~0.1~1uF value connected between pin VCC and GND
7	LX	PWM output connections to output inductor.
8	BS	High side bootstrap capacitor output. Normally ceramic capacitor with 10~22nF value connected between BS and LX.

Electrical Parameters

(T_A=25 °C; V_{EN}=Vin=12V; Vout=3.3V unless noted otherwise)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY						
V_{Vin}	Input DC supply voltage range	-	4.5	-	18	V
V_{out}	Output DC voltage range		0.8		0.75 V_{Vin}	V
I_{VCCSD}	Shut-Down Supply Current	EN/SYNC to GND	-	20	50	uA
Iq	Supply Current (Quiescent)	Iout=0; V_{FB}>1.2V;	-	1.5	4	mA
V_{UVLO}	Input Under-Voltage Lockout Threshold	Vin Rising Vin Falling	- -	3.6 3.4	- -	V V
V_{FB}	Voltage Feedback		788	800	812	mV
I_{FB}	Feedback input current		-	50	200	nA
OSCILLATOR						
F_0	Internal frequency	V_{FB}=0.75V;	0.8	1.0	1.2	MHz
F_{FB}	Fold-back frequency	V_{FB}=0.15V;	-	125	-	kHz
V_{FOLD}	Fold-back tripping level	F_{FB} -> F_0	-	0.16	-	V
D_{MAX}	Maximum Duty Cycle	V_{FB}=0.75V	75	82	-	%
T_{MIN}	Minimum On Time		-	80	-	ns
FEEDBACK						
G_{VEA}	Error Amplifier Voltage Gain		-	500	-	V/V
G_{EA}	Error Amplifier Transconductance	Iout =+/-10uA	-	200	-	uA/V
ENABLE						
V_{EN}	EN Input Threshold	Off Threshold On Threshold	2	-	0.6	V V
V_{HYST}	EN Hysteresis		-	100	-	mV
PROTECTION						
I_{LIMHS}	High Side Current Limit	Peak Source Current	3.5	4.8	-	A
T_{SHDN}	Over Temperature Shutdown	T_J Rising T_J Falling	- -	150 100	- -	°C °C
Tss	Soft Start Interval		-	2.5	-	ms
OUTPUT STAGE						
R_{ONHS}	High Side Switch On Resistance		-	120	-	mΩ
R_{ONLS}	Low Side Switch On Resistance		-	80	-	mΩ

Detailed Description

The IK5302 is a 18V 3A synchronous step-down (buck) converter with two integrated High side and Low side N-LDMOS transistors. The IK5302 implements current control method which provides high stability during operation and fast response during abrupt load change. It operates from a 4.5V to 18V input voltage range and supplies up to 3A of load current. The IK5302 operates on fixed 1Mhz frequency.

Soft Start

The IK5302 has an internal soft start feature to limit in-rush current and ensure the output voltage ramps up smoothly to regulation voltage. A soft start process begins when the input voltage rises to 3.6V and voltage on EN pin is HIGH. In the soft start process, the output voltage is typically ramped to regulation voltage in 2.5ms. The soft start time is set internally. The EN pin of the IK5302 is active HIGH. Connect the EN pin to VIN if the enable function is not used. Pulling EN to ground will disable the IK5302. Do not leave it open.

Steady-State Operation

Under steady-state conditions, the converter operates in fixed frequency and Continuous-Conduction Mode (CCM). Output voltage is divided down by the external voltage divider at the FB pin. The difference of the FB pin voltage and reference is amplified by the internal trans conductance error amplifier. The error voltage, which shows on the COMP pin, is compared against the current signal, which is sum of inductor current signal and ramp compensation signal, at the PWM comparator input. If the current signal is less than the error voltage, the internal high-side switch is on. The inductor current flows from the input through the inductor to the output. When the current signal exceeds the error voltage, the high-side switch is off. The inductor current is freewheeling through the internal low-side N-LDMOS switch to output. The internal adaptive FET driver guarantees no turn on overlap of both high-side and low-side switch.

Output Voltage Programming

Output voltage can be set by feeding back the output to the FB pin by using a resistor divider network. See the application circuit shown in Figure 1. The resistor divider network includes R1 and R2. Usually, a design is started by picking a fixed R2 value and calculating the required R1 with equation below:

$$V_O = 0.8 \times \left(1 + \frac{R_1}{R_2}\right)$$

Some standard value of R1, R2 and most used output voltage values are listed in Table.

VO (V)	R1 (kΩ)	R2 (kΩ)
0.8	1.0	open
1.2	4.99	10
1.5	10	11.5
1.8	12.7	10.2
2.5	21.5	10
3.3	31.1	10
5.0	52.3	10

The combination of R1 and R2 should be large enough to avoid drawing excessive current from the output, which will cause power loss.

Protection Features

The IK5302 has multiple protection features to prevent system circuit damage under abnormal conditions.

Over Current Protection (OCP)

The sensed inductor current signal is also used for over current protection. The peak inductor current is automatically limited cycle by cycle. When the output is shorted to ground under fault conditions, the inductor current decays very slow during a switching cycle because of VO = 0V. To prevent catastrophic failure a high side current limit is designed inside the IK5302. The measured inductor current is compared against a preset voltage which represents the current limit. When the output current is more than current limit, the high side switch will be turned off.

Power-On Reset (POR)

A power-on reset circuit monitors the input voltage. When the input voltage exceeds 3.6V, the converter starts operation. When input voltage falls below 3.4V, the converter shuts down.

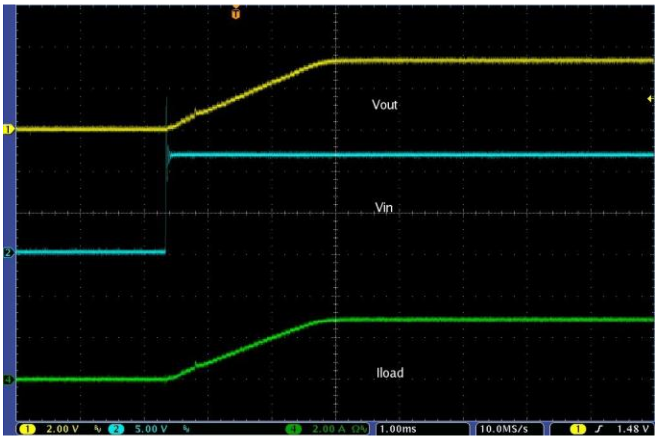
Thermal Protection

An internal temperature sensor monitors the junction temperature. It shuts down the internal control circuit and high side N-LDMOS if the junction temperature exceeds 150°C. The regulator will restart automatically when the junction temperature decreases to 100°C.

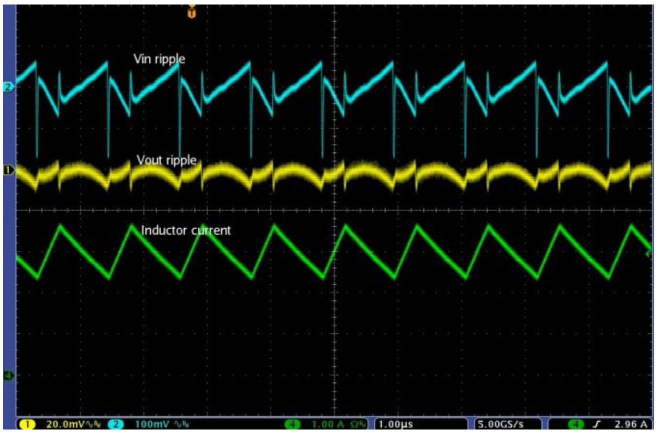
Typical Performance Characteristics

T_A= 25°C, V_{IN}= V_{EN}= 12V, V_{OUT}= 3.3V unless otherwise specified.

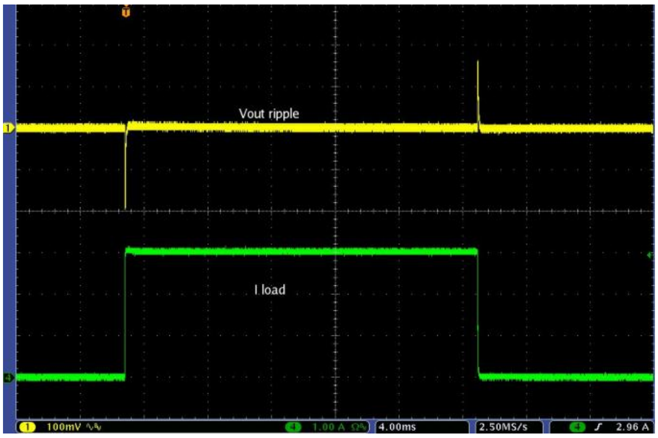
Startup to Full Load



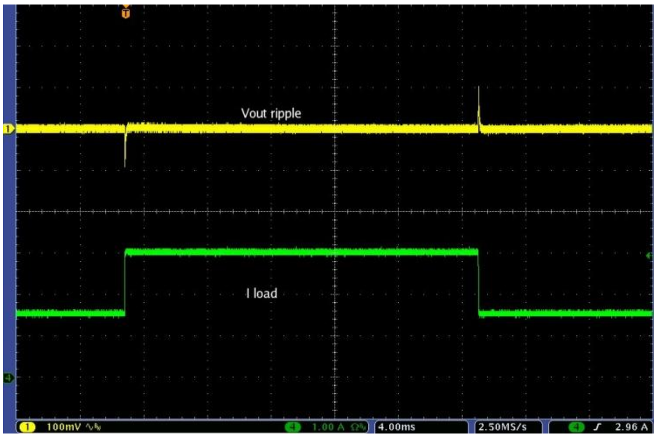
Full Load Operation



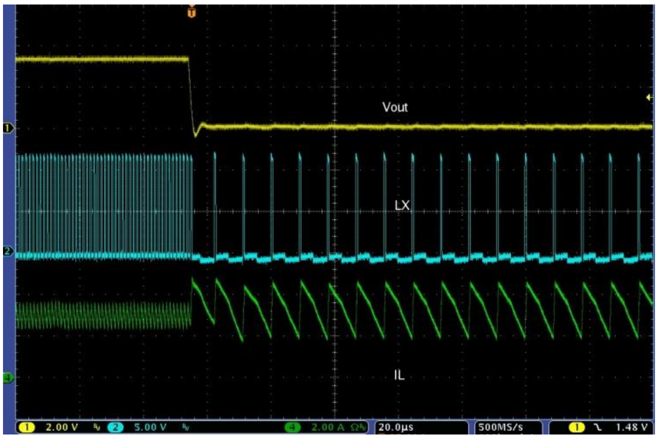
0% to 100% Load Response



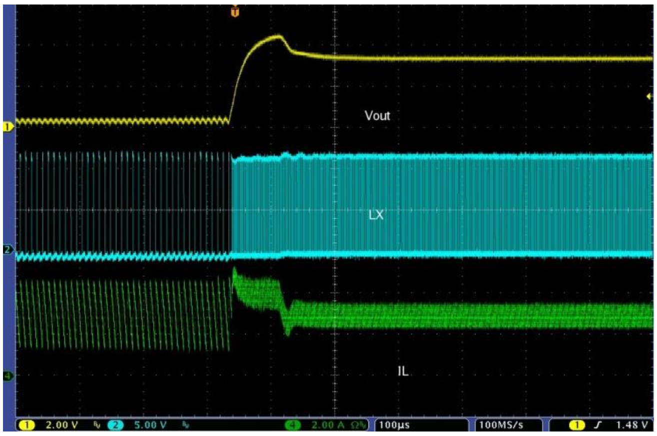
50% to 100% Load Response



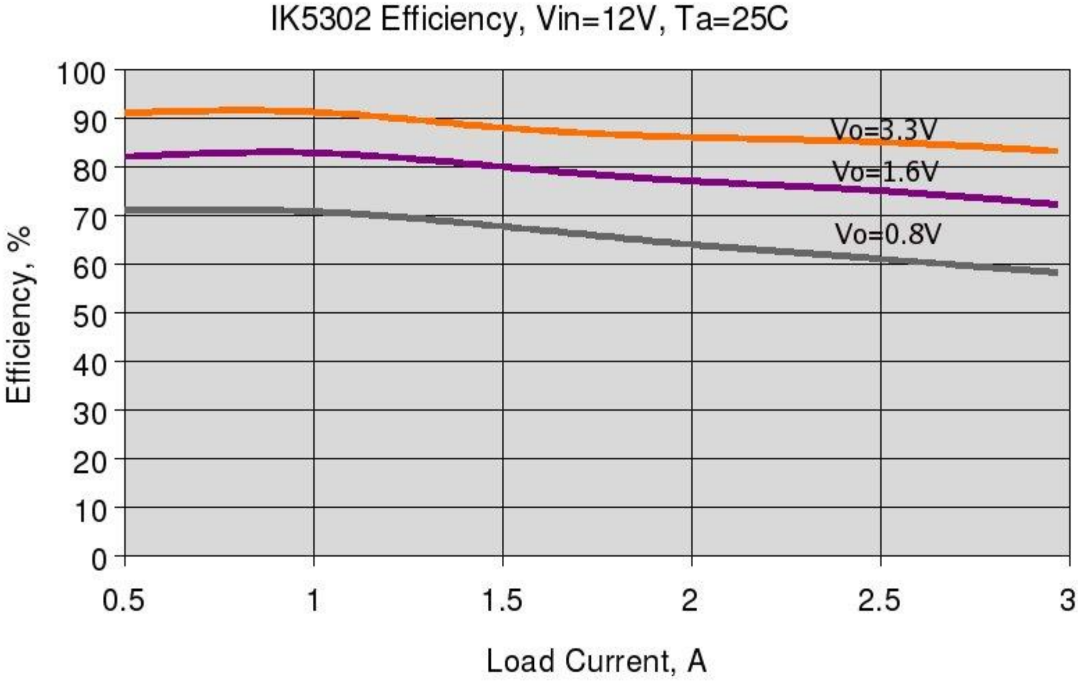
Short Circuit Protection



Short Circuit Recovery



Efficiency


IK5302 Efficiency, Vin=12V, Ta=25C
Efficiency, %
100
90
80
70
60
50
40
30
20
10
0
0.5
1
1.5
2
2.5
3
Load Current, A
Vo=3.3V
Vo=1.6V
Vo=0.8V

Application Information

The basic IK5302 application circuit is show in Figure 1. Component selection is explained below.

Input Capacitor

The input capacitor must be connected to the V_{IN} pin and GND pin of IK5302 to maintain steady input voltage and filter out the pulsing input current. The voltage rating of input capacitor must be greater than maximum input voltage plus ripple voltage.

The input ripple voltage can be approximated by equation below:

$$\Delta V_{IN} = \frac{I_O}{f \times C_{IN}} \times \left(1 - \frac{V_O}{V_{IN}}\right) \times \frac{V_O}{V_{IN}}$$

Since the input current is discontinuous in a buck converter, the current stress on the input capacitor is another concern when selecting the capacitor. For a buck circuit, the RMS value of input capacitor current can be calculated by:

$$I_{CIN\_RMS} = I_O \times \sqrt{\frac{V_O}{V_{IN}}\left(1 - \frac{V_O}{V_{IN}}\right)}$$

For reliable operation and best performance, the input capacitors must have current rating higher than I_{CIN_RMS} at worst operating conditions. Ceramic capacitors are preferred for input capacitors because of their low ESR and high current rating. Depending on the application circuits, other low ESR tantalum capacitor may also be used. When selecting ceramic capacitors, X5R or X7R type dielectric ceramic capacitors should be used for their better temperature and voltage characteristics. Note that the ripple current rating from capacitor manufactures are based on certain amount of life time. Further de-rating may be necessary in practical design.

Inductor

The inductor is used to supply constant current to output when it is driven by a switching voltage. For given input and output voltage, inductance and switching frequency together decide the inductor ripple current, which is:

$$\Delta I_L = \frac{V_O}{f \times L} \times \left(1 - \frac{V_O}{V_{IN}}\right)$$

The peak inductor current is:

$$I_{Lpeak} = I_O + \frac{\Delta I_L}{2}$$

High inductance gives low inductor ripple current but requires larger size inductor to avoid saturation. Low ripple current reduces inductor core losses. It also reduces RMS current through inductor and switches, which results in less conduction loss. Usually, peak to peak ripple current on inductor is designed to be 20% to 40% of output current.

When selecting the inductor, make sure it is able to handle the peak current without saturation even at the highest operating temperature.

The inductor takes the highest current in a buck circuit. The conduction loss on inductor need to be checked for thermal and efficiency requirements.

Surface mount inductors in different shape and styles are available from Coilcraft, Elytone and Murata. Shielded inductors are small and radiate less EMI noise. But they cost more than unshielded inductors. The choice depends on EMI requirement, price and size.

Output Capacitor

The output capacitor is selected based on the DC output voltage rating, output ripple voltage specification and ripple current rating.

The selected output capacitor must have a higher rated voltage specification than the maximum desired output voltage including ripple. De-rating needs to be considered for long term reliability.

Output ripple voltage specification is another important factor for selecting the output capacitor. In a buck converter circuit, output ripple voltage is determined by inductor value, switching frequency, output capacitor value and ESR. It can be calculated by the equation below:

$$\Delta V_O = \Delta I_L \times \left(ESR_{CO} + \frac{1}{8 \times f \times C_O} \right)$$

where,
C_O is output capacitor value, and
ESR_{CO} is the equivalent series resistance of the output capacitor.

When low ESR ceramic capacitor is used as output capacitor, the impedance of the capacitor at the switching frequency dominates. Output ripple is mainly caused by capacitor value and inductor ripple current. The output ripple voltage calculation can be simplified to:

$$\Delta V_O = \Delta I_L \times \left(\frac{1}{8 \times f \times C_O} \right)$$

If the impedance of ESR at switching frequency dominates, the output ripple voltage is mainly decided by capacitor ESR and inductor ripple current. The output ripple voltage calculation can be further simplified to:

$$\Delta V_O = \Delta I_L \times ESR_{CO}$$

For lower output ripple voltage across the entire operating temperature range, X5R or X7R dielectric type of ceramic, or other low ESR tantalum are recommended to be used as output capacitors.

In a buck converter, output capacitor current is continuous. The RMS current of output capacitor is decided by the peak to peak inductor ripple current. It can be calculated by:

$$I_{CO\_RMS} = \frac{\Delta I_L}{\sqrt{12}}$$

Usually, the ripple current rating of the output capacitor is a smaller issue because of the low current stress. When the buck inductor is selected to be very small and inductor ripple current is high, the output capacitor could be overstressed.

Loop Compensation

The IK5302 employs peak current mode control for easy use and fast transient response. Peak current mode control eliminates the double pole effect of the output L&C filter. It greatly simplifies the compensation loop design.

With peak current mode control, the buck power stage can be simplified to be a one-pole and one-zero system in frequency domain. The pole is the dominant pole can be calculated by:

$$f_{p1} = \frac{1}{2\pi \times C_O \times R_L}$$

The zero is an ESR zero due to output capacitor and its ESR. It is can be calculated by:

$$f_{Z1} = \frac{1}{2\pi \times C_O \times ESR_{CO}}$$

where;
C_O is the output filter capacitor,
R_L is load resistor value, and
ESR_{CO} is the equivalent series resistance of output capacitor.

The compensation design is actually to shape the converter control loop transfer function to get the desired gain and phase. Several different types of compensation network can be used for the IK5302. In most cases, a series capacitor and resistor network connected to the COMP pin sets the pole-zero and is adequate for a stable high-bandwidth control loop.

The compensation network design requires several steps:

1. Crossover frequency choice - f_C:

Normally this is 1/5 to 1/15 of switching frequency. Higher value improve transient response but have bigger noise due to wider frequency of interest. Lower value have lower noise, but slower transient response. Basically 1/10 is a optimal choice for most application. So, for 1.0MHz operation f_C=100kHZ.

2. Next step is Rc resistor choice in the compensation network. Value of Rc insure that on crossover frequency loop gain will be equal to unity. We can calculate by the formula:
3.

   *Rc=2*π* f_C*Vout*Col(gmea*Vref*gmps)*

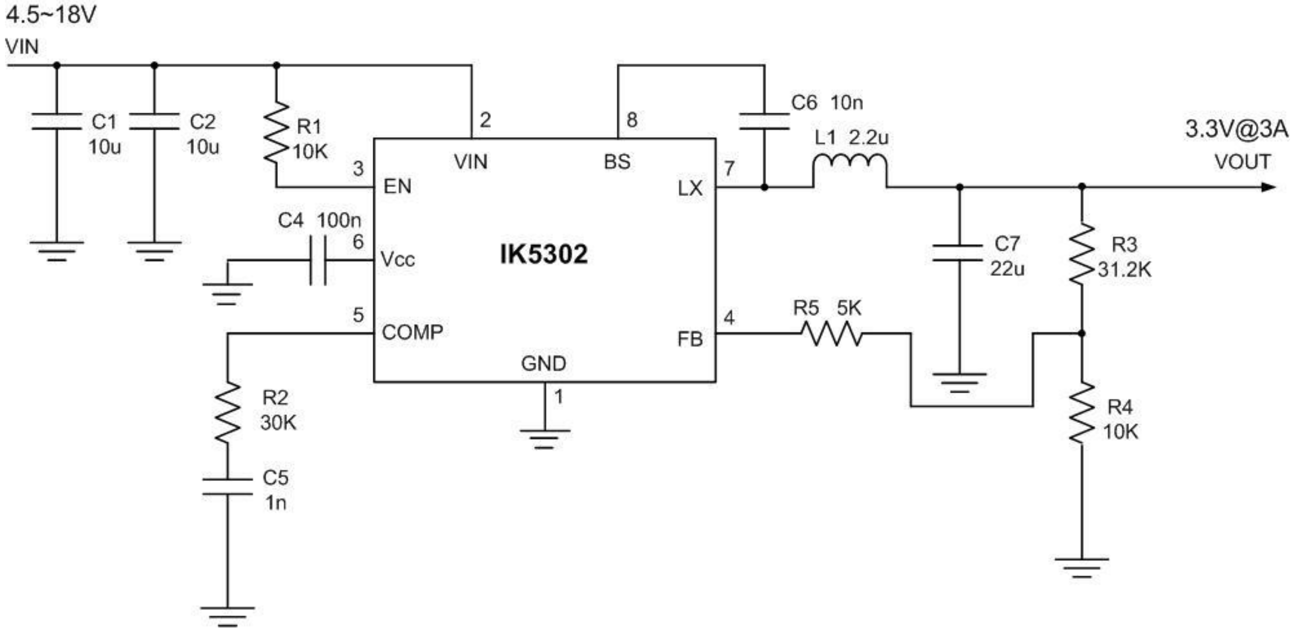
where fC – is crossover frequency;
Vout – is output voltage;
Co – is output capacitance;
Gmea – error amplifier transconductance (200uA/V);
Vref – reference voltage (Vref=0.8);
Gmps – power stage transconductance (~8.6 A/V);

4. Choose compensation capacitance Cc:
   Compensation capacitance defined compensation zero which should be placed on output stage pole. It can be defined as below:

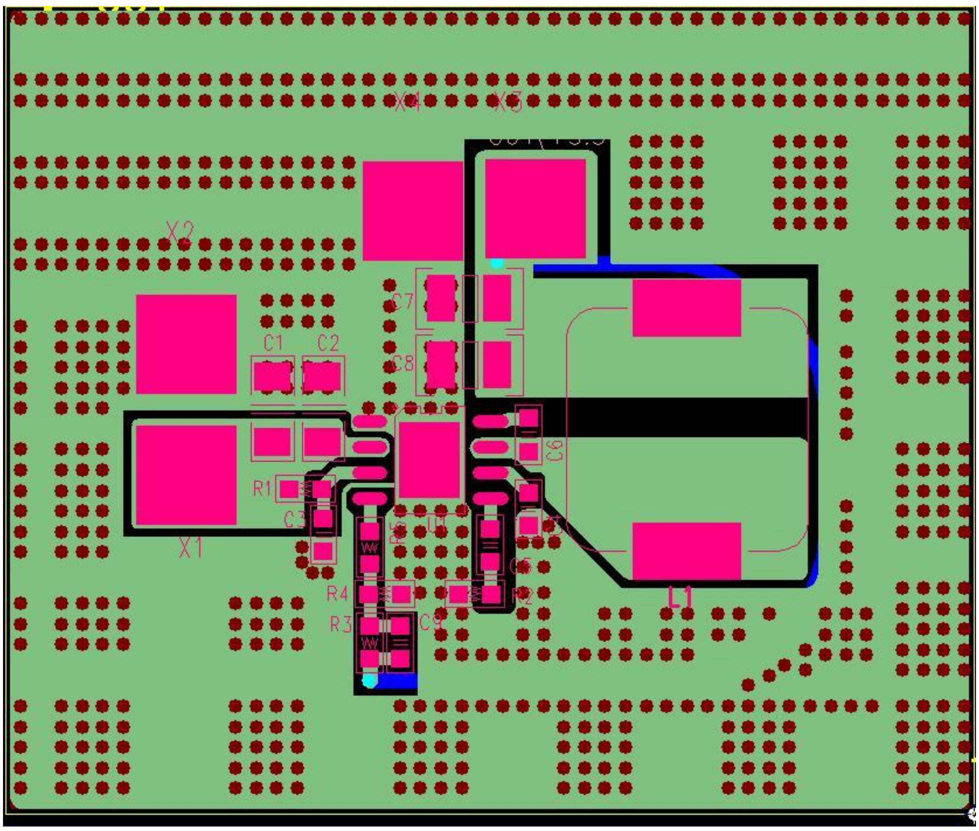
   *Cc=Rl*Co/Rc*

where Rl – is load resistance;
Co – is output capacitance;
Rc – compensation resistance.

Application Information



Demo-Board Schematic



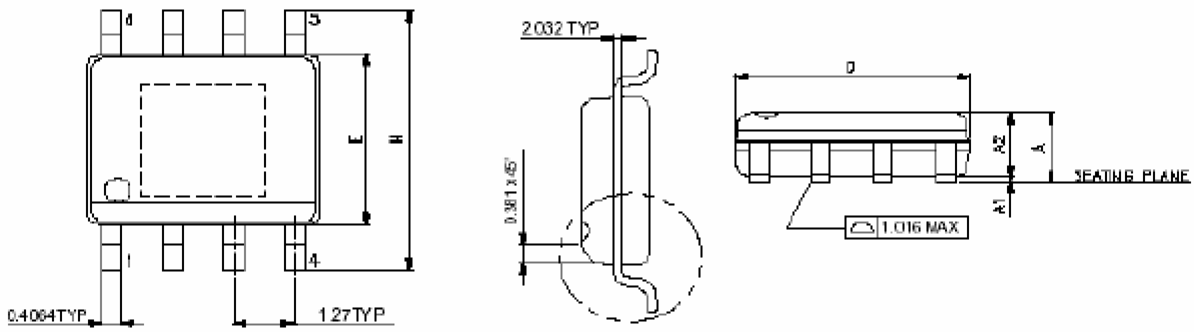
Demo-Board PCB

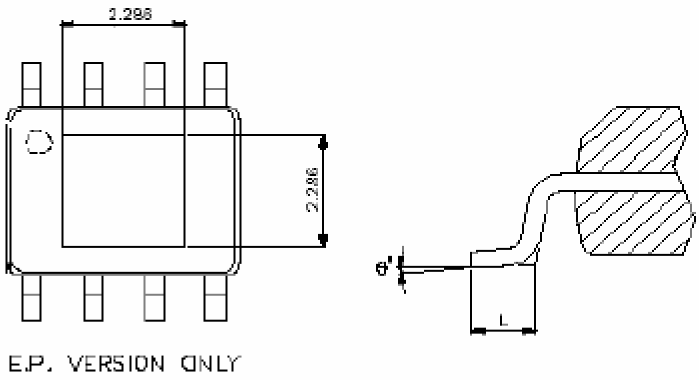
PCB Components List

NO	PARTS NAME	SPECIFICATION	LOCAT NO.	UNIT	Q'TY	VENDOR	REMARKS
1	PCB	Spec:FR-4 4-LAYER		1	EA		
2	Manual Working						
3	LINE FILTER	HPSCBB1207-2R2M	L1	1	EA	Hwa-sung coil	(1.2X1.2X0.8) SMD/T-6A
4	SMD TYPE						
5	CER/CAPACITOR	10uF/25V(1206)	C1,C2	2	EA	samsung-EL	
6	CER/CAPACITOR	22uF/16V(3225)	C7	1	EA	samsung-EL	
7	CER/CAPACITOR	100n/50V(0603)	C4	1	EA	samsung-EL	
8	CER/CAPACITOR	1n/50V(0603)	C5	1	EA	samsung-EL	
9	CER/CAPACITOR	10n/50V(0603)	C6	1	EA	samsung-EL	
10	RESISTOR	5K(0603)	R5	1	EA	samsung-EL	
11	RESISTOR	10KF(0603)	R1,R4	2	EA	samsung-EL	
12	RESISTOR	31.2KF(0603)	R3	1	EA	samsung-EL	
13	RESISTOR	30K(0603)	R2	1	EA	samsung-EL	
14	IC	IK5302	U1	1	EA	samsung-EL	

Package Dimensions

SOP 8





SYMBOLS	MIN.	MAX.
A	1.346	1.752
A1	0.102	0.254
A2	—	1.499
D	4.8	4.978
E	3.81	3.988
H	5.791	6.198
L	0.406	1.27
θ°	0	203.2

UNIT : mm

Note: The unit for the outline drawing is mm.