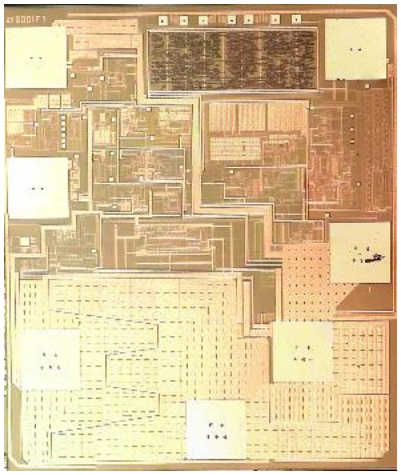
One-chip Multifunction Voltage Regulator

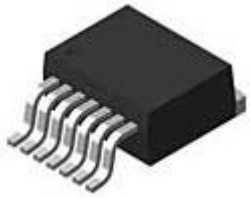
IK8001

FEATURES

- Fully monolithic design
- High side field driver
- LRC function and soft start
- ECU control via L terminal
- Field driver short circuit protection
- Under and overvoltage protection
- Self-start with open L terminal circuit
- Thermal shut down function

IC can be as bare die or TO 263-7 packaged





The IK8001 is a monolithic alternator voltage regulator IC intended for use in automotive application. It includes the control section, the field power stage and the protection against short circuits. IC regulates the output voltage of an automotive generator in close loop by control the field winding current with a Pulse-Width Modulation (PWM) high side driver at fixed frequency. The set-point voltage reference selected by the Engine Control Unit (ECU) via L-terminal protocol is temperature flat. The alternator voltage regulator IC has the standby mode with small current consumption.

Table 1. Device Summary.

Order Code	Operating Temp range, T_J, ºC	Package
IK8001	-40 to 150 ºC	Bare die
IK8001D2T	-40 to 150 ºC	TO 263-7

Contents

1. Schematic diagram and pin description.

1.1 Schematic diagram.

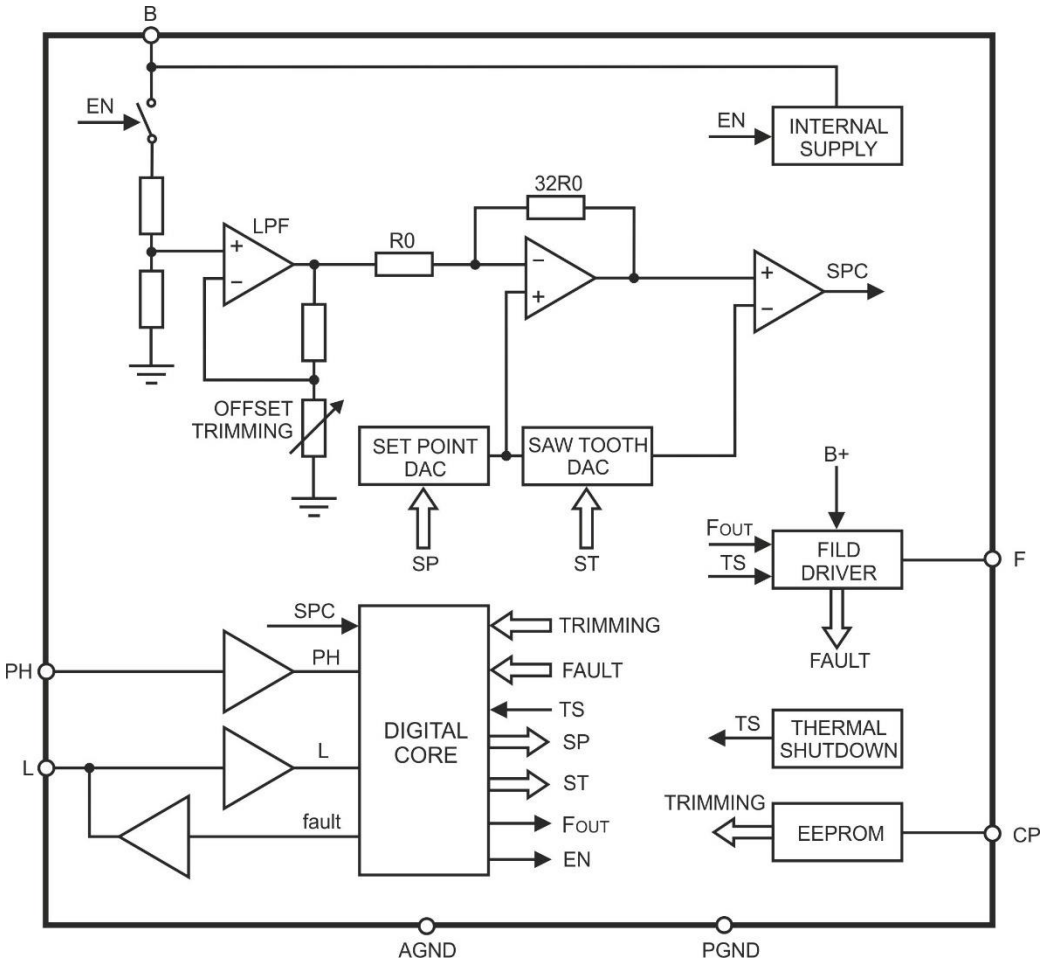


Fig. 1. Block diagram.

1.2. Pin description.

Table 2. Pin description.

Pin	Function	Remark
B	Power supply pin and battery sense	
PGND	Regulator power stage ground	
AGND	Regulator analog part ground	
F	High side driver output	
PH	Phase sense terminal	
L	L-Terminal (PWM signal input coming from ECU)	
CP	Production line programming pin (internal pad)	

2. Electrical specifications.

2.1. Device variants table programmable by EEPROM.

Table 3. Device variants table.

Parameter	Versions	Default
Set Point Voltage, VBDSP, V	13.8	13.8
Gain coefficient	16/24/32/24/48/56/56/64	48
Slope, %	0/-0.3/-0.7/0.2/0.4	-0.3
Rise/Fall Time, µs	15/20/25/40	20
Alternator pole pairs, P	6/7/8	6
Pre-excitation duty cycle, DFPREX, %	6/10/14/18/22/26/30/34	14
Load Response Control Time, TFLRCUP, s	0/2.5/5/8/10	5
Soft Start Time at PH pin, TFsoftph, s	0/2.5/5/8/10	5
Soft Start Time at L pin, TFsoftl, s	0/2.5/5/8/10	5
Load Response Control down ratio, t_{LRDOWN}, s	0.32/0.64/0.96/1.28/1.6/1.92/2.24 (Recommended value: TFLRCUP/4)	1.28
Blind Zone, DF_{LRCBZ}, %	3/6/12	6
Minimum Field Duty Cycle, MFDC, %	3/6	6

2.2. Absolute maximum ratings.

Table 4. Absolute maximum ratings.

(Tj= -40 to 150 °C, unless otherwise specified.)

Symbol	Symbol Parameter Value Unit	Value	Unit
VB_{DC}	DC supply voltage (2 min. @ 25 °C)	24	V
VB_{LD}	Transient supply voltage (load dump) t < 500 ms	45	V
VB_{MAX}	Transient supply voltage with 1A load and t < 1 ms	55	V
L	Transient supply voltage (low energy spikes) ISO7637-1 pulse 1,2,3 / ISO7637-3	55	V
PH	Transient supply voltage (low energy spikes) ISO7637-1 pulse 1,2,3 / ISO7637-3		
Tj	Junction temperature range	- 40 to 150	°C
ESD_{HBM}	ESD HBM (All pins vs. GND)	± 4	kV

2.3 Thermal data.

Table 5. Thermal data.

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
Tj-sd	Thermal shutdown threshold	Temperature to disable F	160	175	190	°C
Tj-sdhy	Thermal shut-down hysteresis	F from OFF STATE (due to thermal shutdown) to ON STATE	Tj-sd - 10	–	Tj-sd - 2	°C

2.4 Electrical characteristics.

Table 6. Electrical characteristics (Tj= -40 to 150 °C, unless otherwise specified.)

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
Pin "B"						
VB_{OVR}	Operating Voltage Range	Normal condition Function Fm	6	–	18	V
V_{UVLOon}	Under Voltage Lock Release		4.5	5.0	5.5	V
$V_{UVLOoff}$	Under Voltage Lock ON		4.0	4.5	5.0	V
$V_{UVLOhyst}$	Under Voltage Lock Out Hysteresis		-	0.5	-	V
IB_{stby}	Stand-by current consumption	VB=12.5V; VPH=0V; L pin floating; T_j =25±5°C	–	–	250	uA
VB_{DSP}	Default Set-Point Voltage	VPH=10Vpp square wave (400hz) , "L" floating @ Tj=30°C "F" duty cycle=50%	13.7	13.8	13.9	V
VB_{SP}	Set-Point Voltage	VPH=10Vpp square wave; (400hz), Duty Cycle @ Tj=30°C; "F" duty cycle=50%	14.5	14.6	14.7	V
			See Fig.6 (C=75% duty,128hz)			
VB_{TD}	Thermal Drift	See fig. 3	-4	0	4	mV/°C
ΔVB_{load}	Regulated Voltage variation with the load @Alternator level	Difference between regulated voltage @ F duty cycle is 10% and @ F duty cycle is 90%	–	–	250	mV
ΔVB_{speed}	Speed regulation @Alternator level	15A load, 2k~10k rpm variation	–	–	100	mV
VB_{wb}	Regulation without battery @Alternator level	10k rpm with full load @ 25°C	-0.5	Vset	+0.5	V
VB_{ovp}	Overvoltage protection threshold	Fault condition, DC = 0%.	16.5		22.0	V
Pin "L"						
VL_{HTh}	High Level Threshold Voltage	Normal condition from ECU	3.1	3.3	3.5	V
		Alarm condition	0.29	0.34	0.39	V
VL_{LTh}	Low Level Threshold Voltage	Normal condition from ECU	1.5	1.7	1.9	V
		Alarm condition	0.11	0.16	0.21	V
VL_{OH}	Generator fault signal threshold	Alarm condition from Alternator @ 10.0 mA			1.0	V

Symbol	Parameter	Test Condition		Min.	Typ.	Max.	Unit
R_{IN}	Input Impedance to Ground	See Fig.6		6	-	10	kΩ
R_{GPD}	Low Side Driver Grounding Resistor	See Fig.6		30	60	90	Ω
fL_{VR}	Valid Frequency Range			115	128	140	Hz
TL_{delay}	Delay time to switch between VB_{DSP} and VB_{SP}	See Fig. 5		30	50	100	ms
DL_{EDCR}	External Duty Cycle Range	See Fig. 4		5	-	95	%
DL_{LTh}	Low Default/External Regions transition threshold			3	5	7	%
DL_{HTh}	High Default/External Regions transition threshold			93	95	97	%
Pin "PH" for multi pole-type							
VP_{HTh}	High voltage threshold	Direct Field		350	400	450	mV
VP_{LTh}	Low voltage threshold			250	300	350	mV
fP_{HPrex}	High Frequency Threshold to exit pre-excitation	Based on 12 poles		64	72	80	Hz
		Based on 14 poles		75	84	93	Hz
		Based on 16 poles		85	96	107	Hz
fP_{LPrex}	Low Frequency Threshold to enter pre-excitation	Based on 12 poles		54	60	66	Hz
		Based on 14 poles		63	70	77	Hz
		Based on 16 poles		72	80	88	Hz
fP_{LRC}	Frequency Threshold to exit/enter in LRC	Based on 12 poles		294	310	326	Hz
		Based on 14 poles		344	362	380	Hz
		Based on 16 poles		392	413	434	Hz
VP_{prTh}	Phase Regulation Voltage threshold			7	8	9	V
IP_{SINK}	Sink current on PH pin	VP=0.3V VP=10V		3 -	5.5 11	8 -	mA
Pin "F"							
VF_{sat}	Field Driver saturation voltage	T_j=130°C; Isink=4.5A		–	–	0.6	V
		T_j=25°C; Isink=7A		–	–	0.55	V
VF_{diode}	Freewheeling diode	IF =6A, T_j=25°C		–	–	2	V
IF_{leak}	Field leakage current	VB=16V; VF=0		–	–	150	μA
IF_{CL}	Field driver current limitation	T_j= -40°C ~ T_j= 150°C	- 40°C	9.5	-	18	A
			27°C	9	-	18	A

Symbol	Parameter	Test Condition		Min.	Typ.	Max.	Unit
			150℃	8	-	18	A
fF_{SW}	Field switching frequency			360	400	440	Hz
TF_{rise}	Field voltage rise time			–	–	25	μs
TF_{fall}	Field voltage fall time			–	–	25	us
DF_{Preex}	Field duty cycle in pre-excitation	Selectable by EEPROM		6 /10 / 14 / 18 / 22 / 26 / 30 / 34			%
$DF_{Preexself}$	Field duty cycle in pre-excitation at Self-start mode			14			%
TF_{LRCUP}	Load Response Control Time (from 0% to 100% DC)	Selectable by EEPROM		0 / 2.5 / 5 / 8 / 10			s
TF_{soft}	Soft Start after cranking Time(from0% to 100% DC)	Selectable by EEPROM		0 / 2.5 / 5 / 8 / 10			s
DF_{LRCBZ}	Blind Zone	Selectable by EEPROM		3 / 6			%
							%
MFDC	Minimum Field Duty Cycle			5	-	7	%
T_{alarm_val}	Fault or Recovery validation time			0.9	1	1.1	S
V_{under_vol}	Undervoltage warning @ under 9.5 of VB & fPH > 300hz			8.0	9.0	10.0	V
TF_{retry}	Retry time in case of over-current			20	25	30	ms
FD_{pk}	Peak Duty Fluctuation	0~100% load @2500 rpm, alternator level				10	%

3. Brief functional description

The device, supplied by the battery through “B” pin, remains in “stand-by” condition with a low current consumption until there is no activity on the pins “L” or “PH” .

When the switch "Key" is closed the ECU communicates via L-Terminal protocol through “L” pin (i.e. signal freq. on “L” pin 128Hz) the device exits “stand-by” condition and goes in “pre-excitation” characterized by an activity on “F” pin with fixed frequency (fF_{SW}) and duty cycle (DF_{Preex}).

The device remains in “pre-excitation” until the alternator does not run. When an activity is sensed on “PH” pin (i.e. $VPH>VP_{HTh}$ and $fPH>fP_{HPrex}$) the device starts to regulate in according with Fig.6.

Another possibility that the device has to start to regulate is the “self start”. In this way, although there is no activity on pins “L” (for example due to connector open), if an activity is sensed on “PH” pin (i.e. $VPH>VP_{HTh}$ and $fPH>fP_{HPrex}$) the device goes in “self start” characterized by an activity on “F” pin with fixed frequency (fF_{SW}). When the frequency on “PH” pin rises above fP_{LRC} the device starts to regulate.

The regulator stops to regulate when the frequency on “PH” pin falls below fP_{LPrex}. If there is activity on “L” pins the device stays in “pre-excitation” otherwise comes back in “stand-by”.

Alarm detection

The device goes into Alarm (Fault) mode after the validation time (T_{alarm_val}) if one of the conditions in the below table is verified.

Table 7. Alarm Detection.

Detection condition	Related pin
$VPH<VP_{HTh}$ or PH frequency < fP_{LPrex}	No activity on “PH” pin
$VPH< VP_{prTh}$ and $VB<(VB_{DSP},VB_{SP})$	“F” driver or its connection degraded
$IF>IF_{CL}$	“F” shortened to “GND” (Over-current on “F” driver)
VB=VF @Field-FET off	“F” shortened to “B”
$VB>VB_{ovp}$	Battery sensor on “B” pin or “F” driver degraded
VB_{under_vol} > VB & fPH > fP_{LRC}	B+ voltage is under VB_{under_vol}

Load Response Control function (LRC)

When an electrical load is applied in the system application, a drop in the regulated voltage (VB) occurs and the alternator reacts increasing output current.

If the LRC function is active then the alternator output current is controlled by the Field current variation strategy that is directly linked to the duty cycle on Field signal.

The LRC function can operate when the alternator runs at low speed (the “PH” signal frequency as to be lower than fP_{LRC}).

When the LRC function is required, the duty cycle increase slowly with the defined slope DF_{LRCUP} starting with the previous duty cycle increased by the fixed value DF_{LRCBZ}.

The actual duty cycle management during a LRC insertion is shown in the figure 2.

Soft Start Function after engine cranking (TF_{soft})

After engine cranking and the speed of alternator above fP_{HPrex}, the voltage regulator shall limit the rate of increase of the field duty cycle to avoid sudden increases in engine load. This limitation rate is known as Load Response Control (LRC).

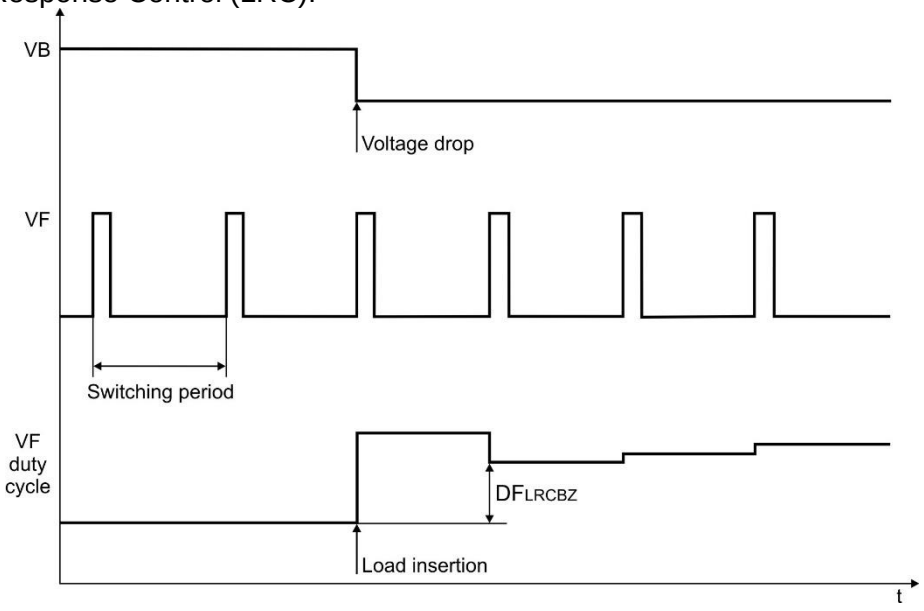


Fig. 2. Duty cycle management during LRC insertion.

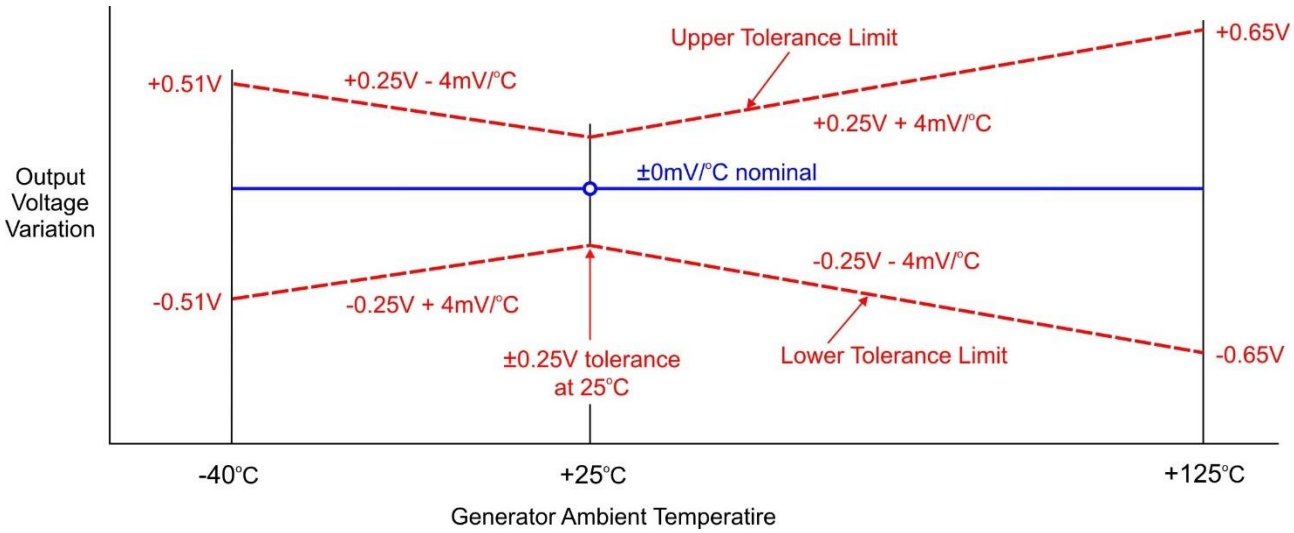


Fig. 3. Temperature compensation.

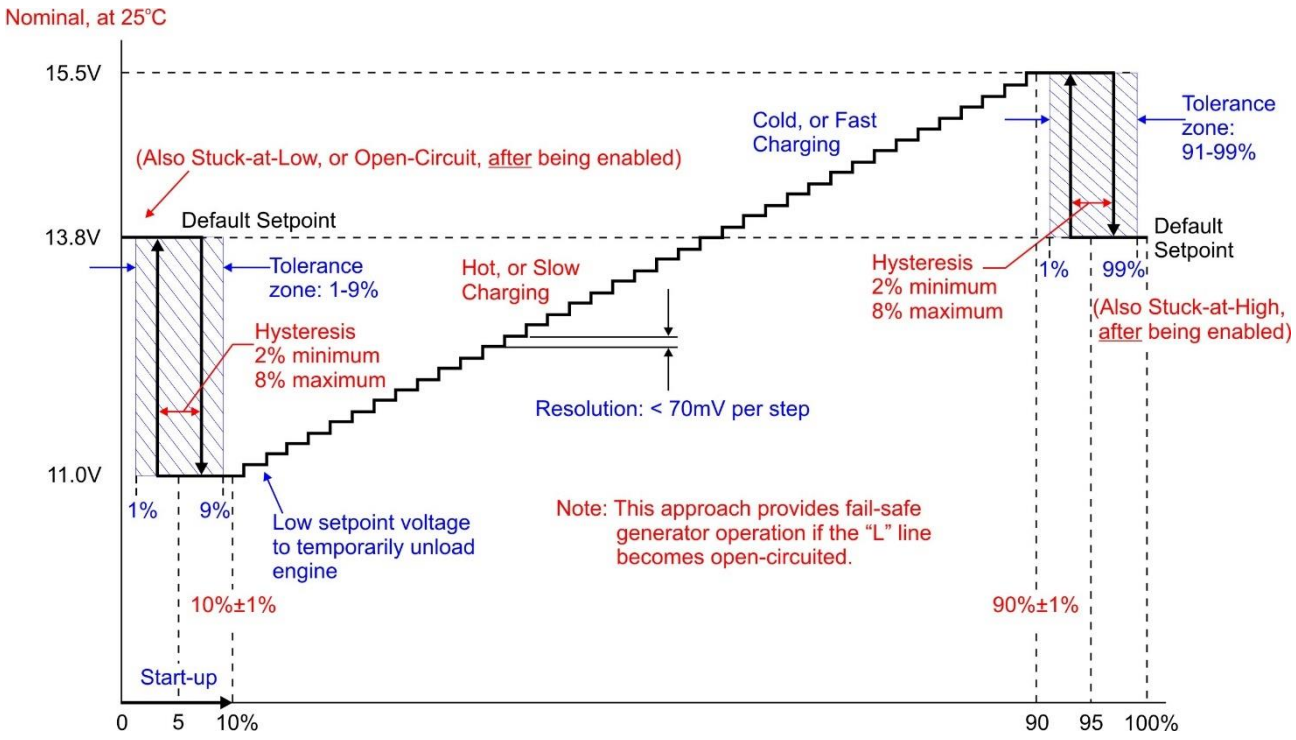


Fig. 4. Set-point voltage for RVC.

V_{SET} can calculate by formula:

$$V_{SET} = 0.05625 * L_{DUTY} + 10.4375 \text{ (for } L_{DUTY} \text{ from 10\% to 90\%).}$$

The slope of V_{SET} selects by EEPROM – slope trimming bits.

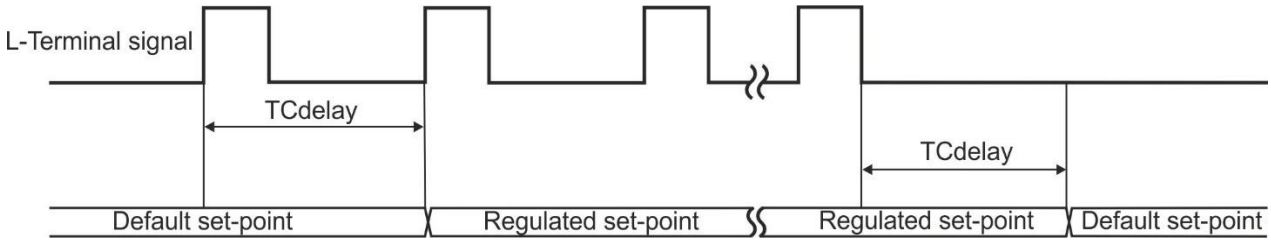


Fig. 5. L terminal wave form.

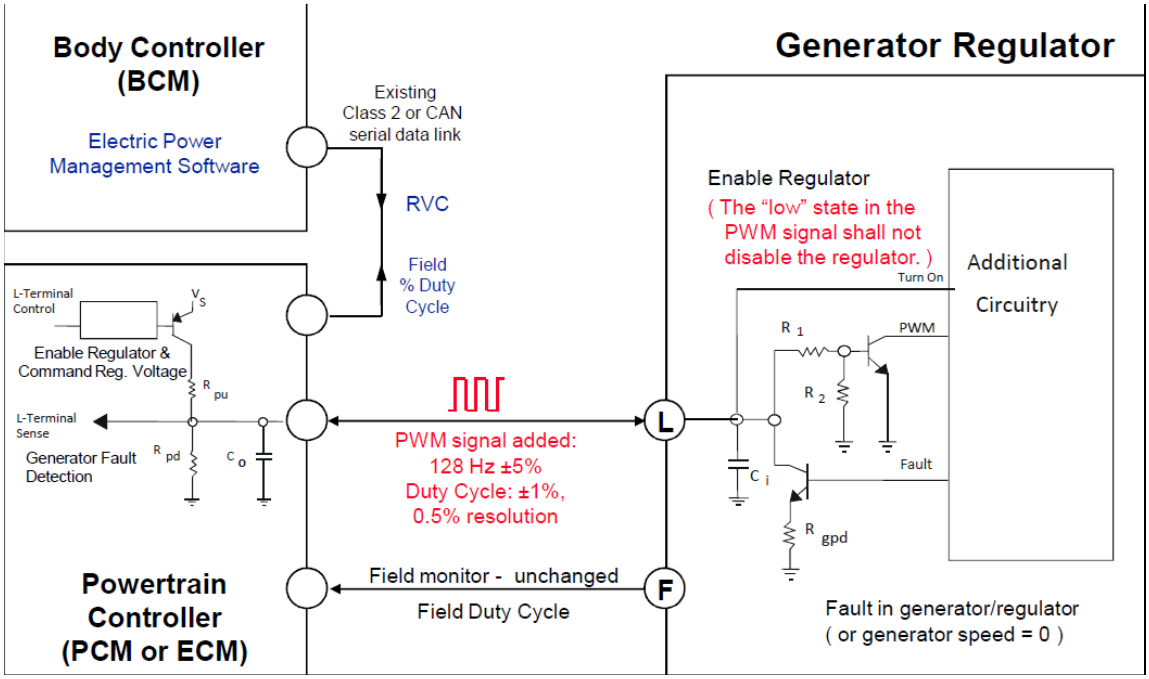


Figure 6. Circuit for L-terminal of RVC.

4. Application chart.

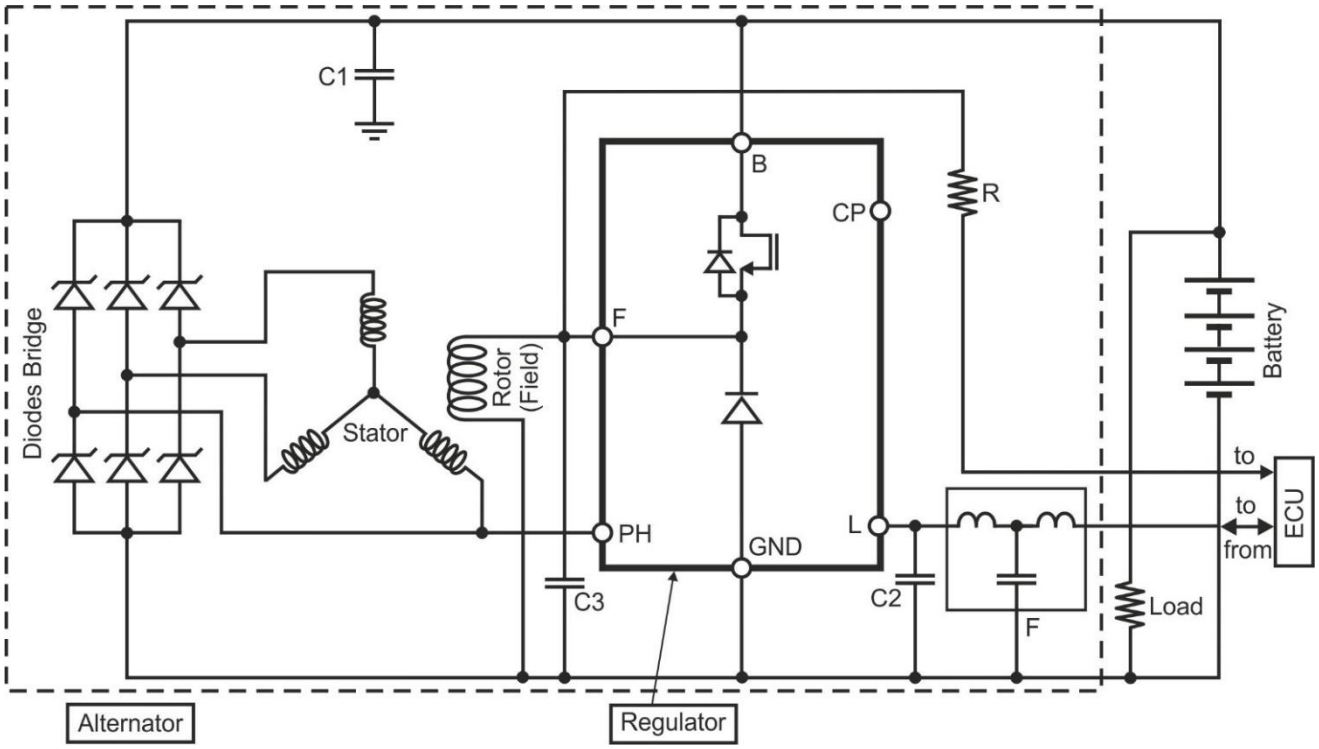


Fig. 7. Application circuit.

Notes:

Rectification diodes should have the break down voltage more 22 V and less 27 V. In opposite case the IK8001 should be protected by TVS. Operation voltage for TVS should be more 20 V but break down TVS voltage should be between 25 V and 35 V.

Parasitic resistance on pin B should be less 20 mOhm and on pin GND should be less 10 mOhm.

Recommended:
C1 = 2.2 uF + 2.2 uF + 4.7 uF
C2 = 10 nF;
C3 = 47 nF;
R = 10 kOhm.
F is three terminal filter ACH32C-222 by TDK company

5. EMC Test specification.

This IC has to comply with following guideline of EMC test. Please see ISO7637-2 and ISO7637-3 for details.

4.1 Guideline of transient test for B-terminal.

Table 8. Requirements Levels for the Immunity to Transients on Power Lines.

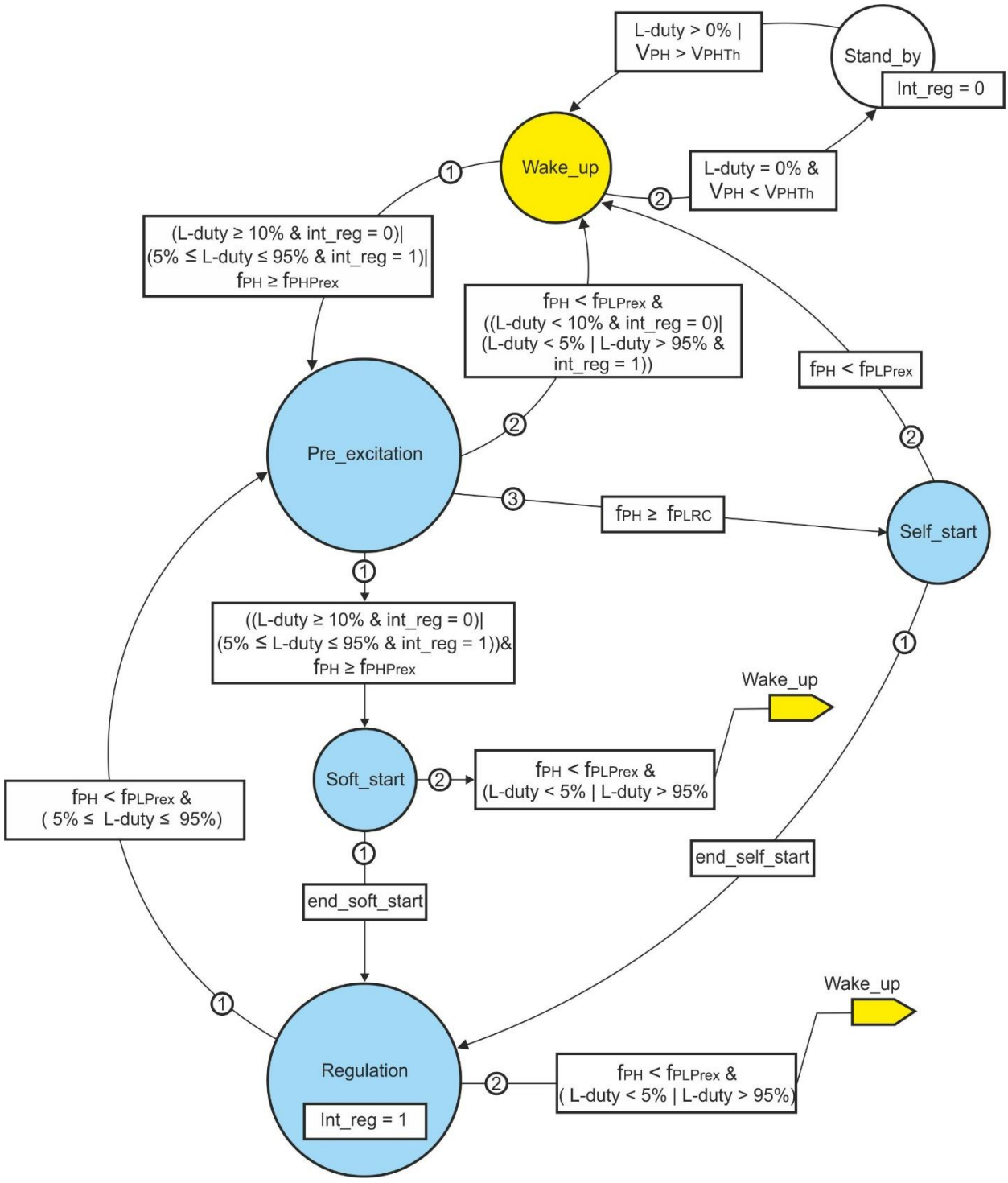
Pulse Number	Level	Minimum Number of Pulses or Application Time	Pulse Cycle Time		Comments
1	Us = - 150Vpeak	500 pulses	0.5s	5s	One or more functions of the DUT can go beyond specified tolerance as long as all functions return within normal limits after the exposure is removed. Memory functions shall perform as designed.
2a	+50Vpeak	500 pulses	0.5s	5s	2Ω transient generator internal source impedance
2b	+10Vpeak	10 pulses	0.5s	5s	There shall be 10 pulses, beginning at 200 ms pulse width, then increasing pulse width by 200 ms steps until 2000 ms is achieved.
3a	-200Vpeak	10 minutes	90ms	110ms	Injection level established into a 50 ohm load (as opposed to the open-circuit measurement as specified in ISO 7637-2).
3b	+100Vpeak	10 minutes	90ms	110ms	Injection level established into a 50 ohm load (as opposed to the open-circuit measurement as specified in ISO 7637-2).
4	ISO 7637-2	1 pulse of each severity level	0.5s	15s	Voltage levels and Performance Criterion for Pulse 4 (crank pulse).
5b	peak	10 pulses	15s	2min	No permanent DUT performance deviations shall be observed after exposure to a load dump pulse with a suppressed open circuit voltage of (34+0/-1)V, Ri = 2Ω.
7	-50Vpeak	500 pulses	0.5s	5s	2Ω transient generator internal source impedance

5.2 Guideline of transient test for L terminal

Table 9. Requirements of Coupling Clamp and (optional) Direct Pin Capacitive Coupling (DCC).

Pulse No.	Level (Vpeak)[Note 1]	Application Time	Default Time Between Pulses	(Optional) DCC Coupling Capacitance
3a	-450	10 minutes	90 ms	220 pF
3b	+450			

6. State Diagram (For reference only).



Note:

1. Stand_by mode means low consumption current state;
2. Int_reg = 0 is enabling mode, Int_reg = 1 is running mode.
3. Wake_up mode means Field Duty = 0 and IC monitors L and PH pins;
4. Pre-excitation mode means: DF=6%, 10%, 14%, 18%, 22%, 26%, 30%, 34%. Value of DF is selected by EEPROM.
5. End_soft_start (end_self_start) means DF achieves 100% or VB=VBsp
6. Regulation mode corresponds with Figure 4;
7. Alarm mode corresponds with Table 7.

Table 10. Operating mode IK8001 vs L-duty and fPH.

Mode	L-duty, %	Frequency PH (fPH)		
		$0 \le fPH < fP_{XPrex}$	$fP_{XPrex} \le fPH < fP_{LRC}$	$fPH \ge fP_{LRC}$
Enabling (Engine start-up with rpm ramping up)	0≤L-duty<10	Field off	Pre-excitation	Normal regulation (Self start)
	L-duty≥10	Pre-excitation	Normal regulation (Soft start, LRC)	Normal regulation
Running (Generator has previously been enabled)	0≤L-dutyt<5	Field off	Normal regulation (LRC)	Normal regulation
	5≤L-duty≤95	Pre-excitation	Normal regulation (LRC)	Normal regulation
	L-duty>95	Field off	Normal regulation (LRC)	Normal regulation

Note:

1. fPXPrex=fPHPrex for exit in pre-excitation mode.
2. fPXPrex=fPLPrex for enter in pre-excitation mode.
3. Setpoint voltage in normal regulation mode is adjusted proportional to L-duty in accordance with Figure 4.

Table 11. Operating mode IK8001 vs fL frequency and fPH frequency (For reference only).

Generator mode	Frequency L (fL)	Frequency PH (fPH)		
		$0 \le fPH < fP_{XPrex}$	$fP_{XPrex} \le fPH < fP_{LRC}$	$fPH \ge fP_{LRC}$
Enabling (Engine start-up with rpm ramping up)	$1Hz \le fL \le fL_{VALID\ MIN}$ for all L-duty	Field off	Pre-excitation	Normal regulation, Self-start, Default set-point
	$fL_{VAID\ MAX} \le fL \le 1KHz$ for all L-duty	Field off	Pre-excitation	Normal regulation, Self start, Default set-point
	$115Hz \le fL \le 140Hz$	According mode IK8001 vs L-duty and fPH (see Table 10)		
	$fL < 1Hz$ & $t_{high\ level} > 1s$	Pre-excitation if L – high; Field off if L – low.	Normal regulation, Soft start, LRC, Default set-point.	Normal regulation, Default set-point.
Running (Generator has previously been enabled)	$1Hz \le fL \le fL_{VALID\ MIN}$ for all L-duty	Field off	Normal regulation, LRC, Default set-point.	Normal regulation, Default set-point
	$fL_{VAID\ MAX} \le fL \le 1KHz$ for all L-duty	Field off	Normal regulation, LRC, Default set-point.	Normal regulation, Default set-point
	$115Hz \le fL \le 140Hz$	According mode IK8001 vs L-duty and fPH (see Table 10)		
	$fL < 1Hz$ & $t_{high\ level} > 1s$	Field off	Normal regulation, LRC, Default set-point.	Normal regulation, Default set-point

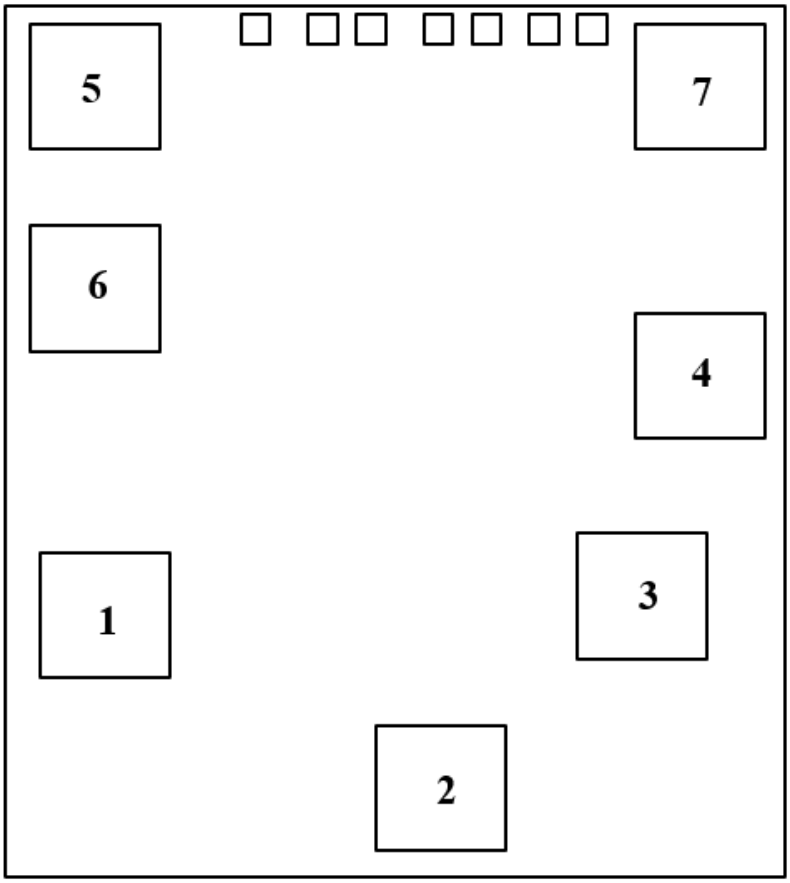
Note:

1. $fP_{XPrex} = fP_{HPrex}$ for exit in pre-excitation mode.
2. $fP_{XPrex} = fP_{LPrex}$ for enter in pre-excitation mode.

7. Recommendation for assembly of chip.

Pad location.

Chip size: X = 4 500 um, Y = 5 300 um.



The chip size is given without size of the Scribe Line**.**

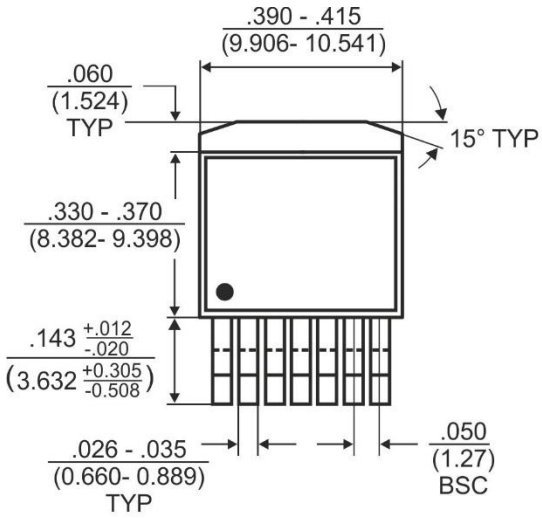
Coordinates of the Pads (“POR” layer)

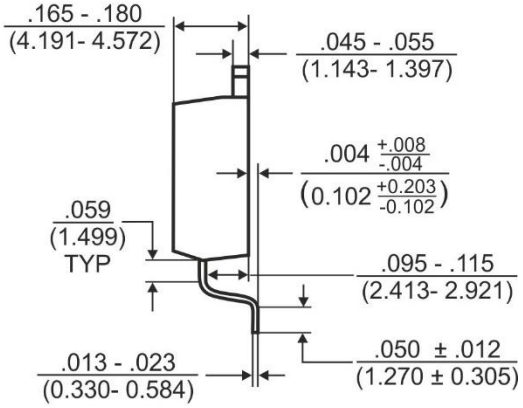
PAD Number	X, um	Y, um	Pin Name
1	161.6	949.1	B
2	2045.6	121.6	F
3	3048.6	1010.4	PGND
4	3708.6	2130.4	AGND
5	3671.6	4436.6	CP
6	55.6	2913.9	PH
7	53.4	4387.4	L

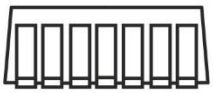
Wire bonding pad size are:
1. 700.0 x 700.0 um on metal layer “MET3”;
2. 690.8 x 690.8 um on POR layer.

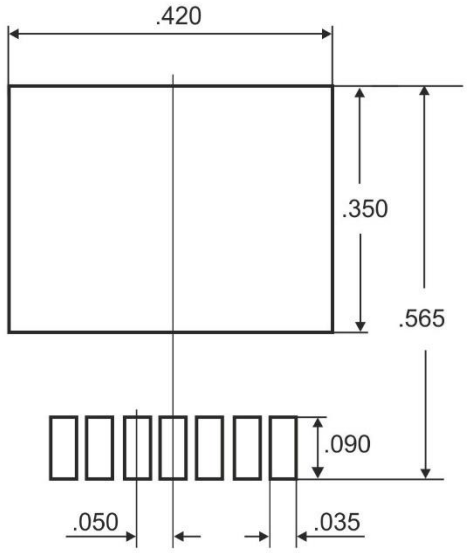
Note:
1) Wafer thickness is 406 um typical.
2) Back side of wafer is under GND voltage. Back side metal should be connected to GND pad.
3) Die bonding should be made by soldering alloy with melting point more 220°C or silver epoxy compound with thermal conductivity more 50 W/K*m.
   Recommended to use the tin-silver-copper alloy with 3.0-4.0% of silver.
4) Back side metal is – NiV 2000 Å / Ag 1500 Å.
5) Top level metal thickness is 2.7 um typical.
6) Wire thickness should be more 0.2 mm.

8. Package information and pinout.









RECOMMENDED SOLDER PAD LAYOUT
NOTE:
1. DIMENSIONS IN INCH (MILLIMETER)
2. DRAWING NOT TO SCALE

Table 12. Pinout and description.

Pin	Symbol	Description
1	CP	For EEPROM programming
2	L	L-Terminal (PWM signal input coming from ECU)
3	PH	Phase sense input
4	GND	Regulator ground
5	B	Device power supply and Battery voltage sensing
6	NC	Not connect
7	F	High side driver output to control the Field current

9. Revision history.

Date	Rev	Changes	Remark
2012 Oct.11	00	Page 1: New device name Page 1, 3 : Fm is excluded Page 4: Exclude term ISP, ESP, fPss Page 4: Added description of Alarm detection Page 6: Changed table 4,5 (exclude Fm and Smax) Page 7: Replace VBISP and VBESP to VBDSP and VBSP Page 7: Replace VBITD and VBETD to VBTD Page 7: Replace VBintOvp and VBextOvp to VBovp Page 8: Changed description for TCdelay Page 8: Excluded fPss Page 8: Fm is excluded Page 11: Fig 7 is updated Page 11: Fig 8 is exlluded; fig 8-1 is renamed to fig.8 Page 13: Fm, Fr, L are excluded Page 13: Excluded “Package Information” Page 14: New state diagram	
2012 Oct.24	01	Page 6: Under Voltage Lock Out ON ➔ Under Voltage Lock Release Page 6: Under Voltage Lock Out OFF ➔ Under Voltage Lock ON Page 6: Under Voltage Lock Out ON 5 / 5.5 /6.0 ➔ 4.5 / 5 / 5.5 Page 6: Under Voltage Lock Out OFF 4.5 / 5.0 / 5.5 ➔ 4.0 / 4.5 / 5.0 Page 8: fPLRC 12 Poles 263 / 310 / 356 ➔ 294 / 310 / 326 fPLRC 14 Poles 307 / 362 / 415 ➔ 344 / 362 / 380 fPLRC 16 Poles 351 / 413 / 475➔ 392 / 413 / 434 22. Page 9: TFretry 35 / 40 / 45 ➔ 20 / 25 / 30	
2013 Oct. 06	02	Page 7: New value the VLHTh, VLLTh, , fLVR Page14: State diagram Page 4: Table 3. Exclude activity on pin-L for alarm condition.	
2013 Nov. 19	03 Ver.E Rev.1	Page 14: Changed State diagram in accordance requirement of GM standard (enable mode) Add Page 15: Operating mode IK8001E vs L-duty and fPH	
2014 Jan. 16	04 Ver.E Rev.1	Page 8. Changed Phase Regulation Voltage Threshold VPprTh min. 8V → min. 7V, typ. 8V, max. 9V. Page 14. Changed State diagram in accordance requirement of GM standard (enabling mode and running mode)	
2014 Jul. 24	05 Ver.F Rev.0	Page 7. Changed the condition for measuring stand-by current consumption. Tj =25±5% Page 8. Added new parameter VPLTh “Low voltage threshold”. Added new parameter IPSINK “Sink current on PH pin”. Page 9. Added new value for field duty cycle in pre-excitation mode 6%, 10%, 14%, 18%, 22%, 26%, 30%, 34%.	

		Page 15. Added new explanation for pre-excitation mode Page 17. Added “Operation mode IK8001 vs fL frequency and fPH frequency	
2014 Nov.06	06 Ver.F Rev.1	Page 8. Added value for parameter IPSINK. Page 9. Added parameter DFPreexself “Field duty cycle in pre-excitation at self-start mode”.	
2017 Jun. 20	07 Ver.F Rev.2	1.Added package solution. 2. All pages upgraded.	
2018 May 24	08 Ver.F Rev.3	1. Page 1. Added die photo. 2. Page 10. Added V_{SET} calculation formula.	
2021 Jan12	09 Ver.F Rev.4	1. Page 4. Added EEPROM options Table.	