# 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

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 |
| IK8001D0T | -40 to 150 ºC | TO 220-7 |
| IK8001D2T | -40 to 150 ºC | TO 263-7 |

**Contents**

## 1. Schematic diagram and pin description.

### 1.1 Schematic diagram.

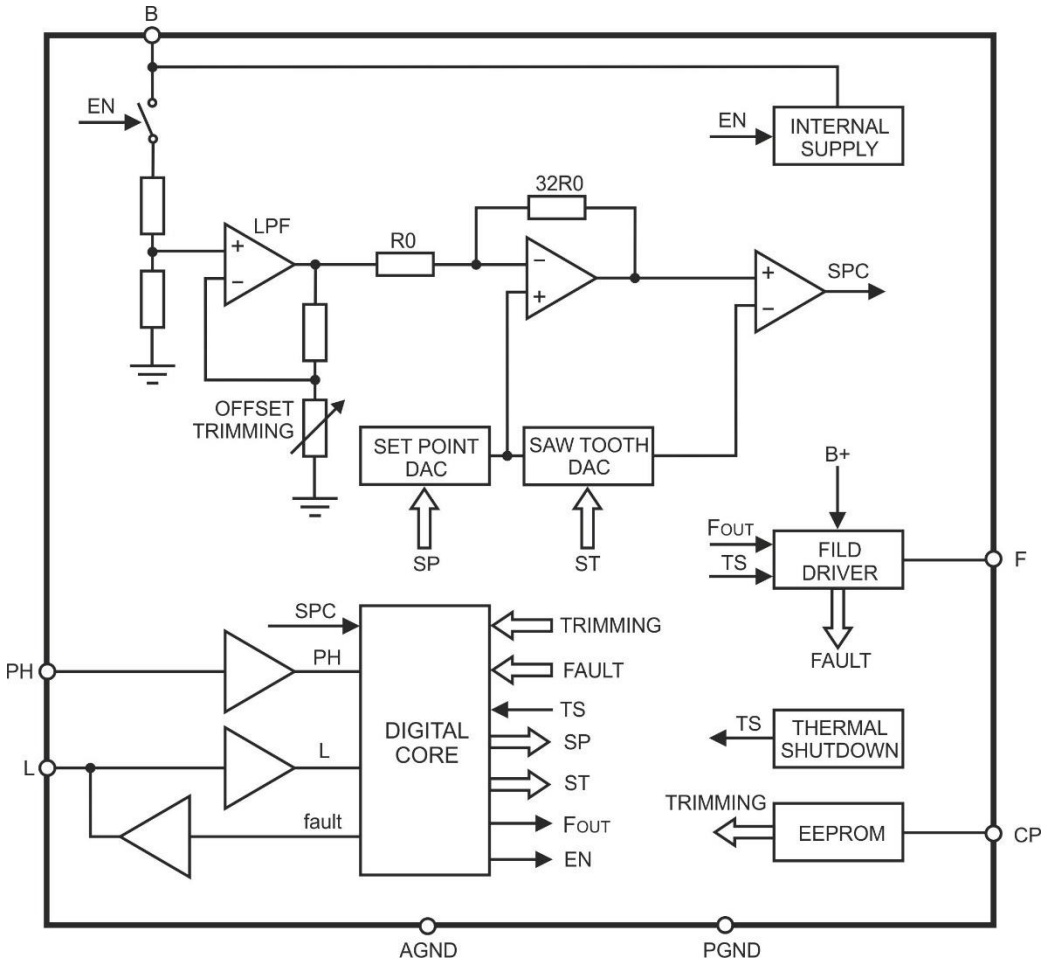



Fig. 1. Block diagram.

### 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. Absolute maximum ratings.

**Table 3. 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 |

### 2.2. Thermal data.

**Table 4. 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 |

## 2.3 Electrical characteristics.

**Table 5. 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<br>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;<br>L pin floating; $T_j$ =25±5°C | – | – | 250 | uA |
| $VB_{DSP}$ | Default<br>Set-Point Voltage | VPH=10Vpp square wave (400hz) ,<br>"L" floating @ Tj=30°C<br>"F" duty cycle=50% | 13.7 | 13.8 | 13.9 | V |
| $VB_{SP}$ | Set-Point Voltage | VPH=10Vpp square wave; (400hz),<br>Duty Cycle @ Tj=30°C;<br>"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 |
| $\Delta VB_{load}$ | Regulated Voltage variation with the load<br>@Alternator level | Difference between regulated voltage<br>@ F duty cycle is 10% and<br>@ F duty cycle is 90% | – | – | 250 | mV |
| $\Delta VB_{speed}$ | Speed regulation<br>@Alternator level | 15A load, 2k~10k rpm variation | – | – | 100 | mV |
| $VB_{wb}$ | Regulation without battery<br>@Alternator level | 10k rpm with full load<br>@ 25°C | -0.5 | Vset | +0.5 | V |
| $VB_{ovp}$ | Overvoltage protection threshold | Fault condition,<br>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<br>VP=10V | | 3<br>- | 5.5<br>11 | 8<br>- | 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 | | | %<br>% |
| 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 6. 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).

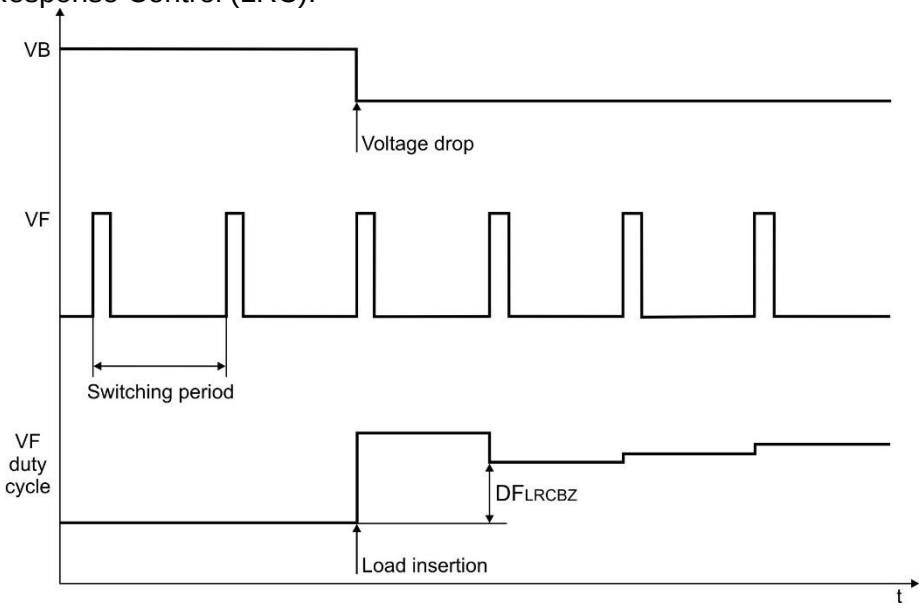



Fig. 2. Duty cycle management during LRC insertion.

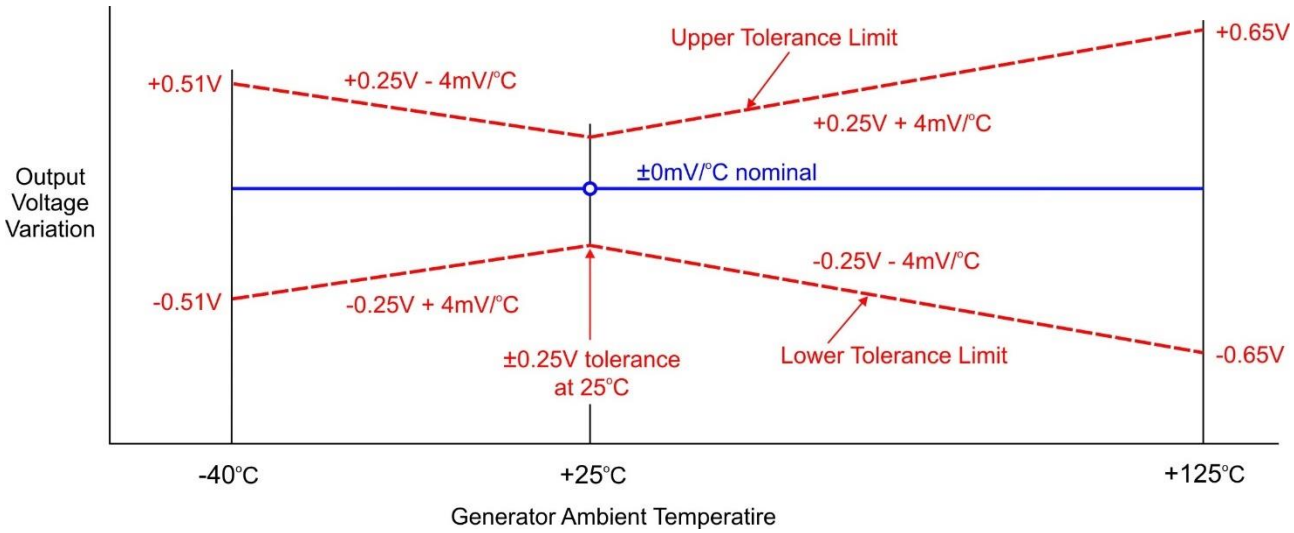



Fig. 3. Temperature compensation.

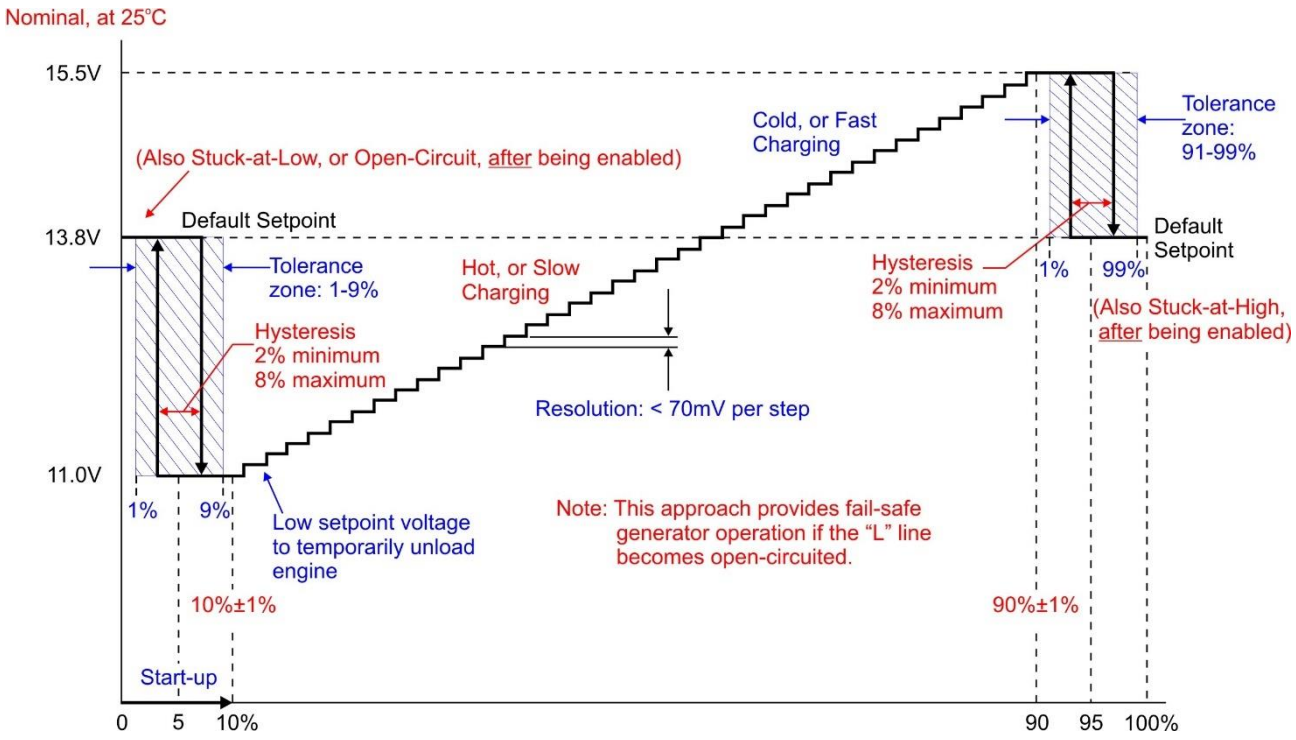



Fig. 4. Set-point voltage for RVC.

VSET can calculate by formula:

$$V_{SET} = 0.05625 * L_{DUTY} + 10.4375$$

The slope of VSET selects by EEPROM – slope trimming bits.

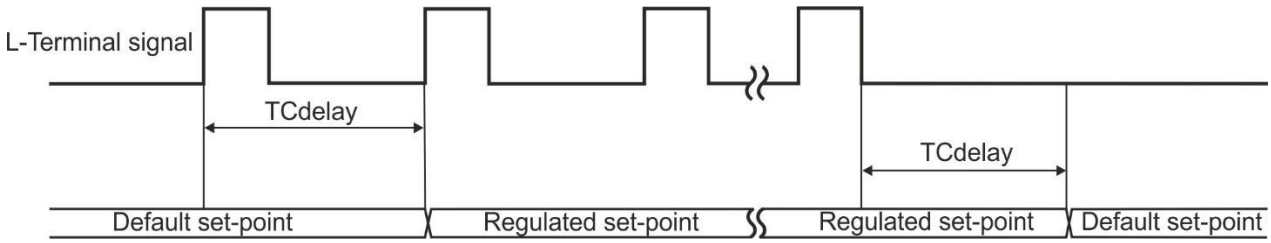



Fig. 5. L terminal wave form.

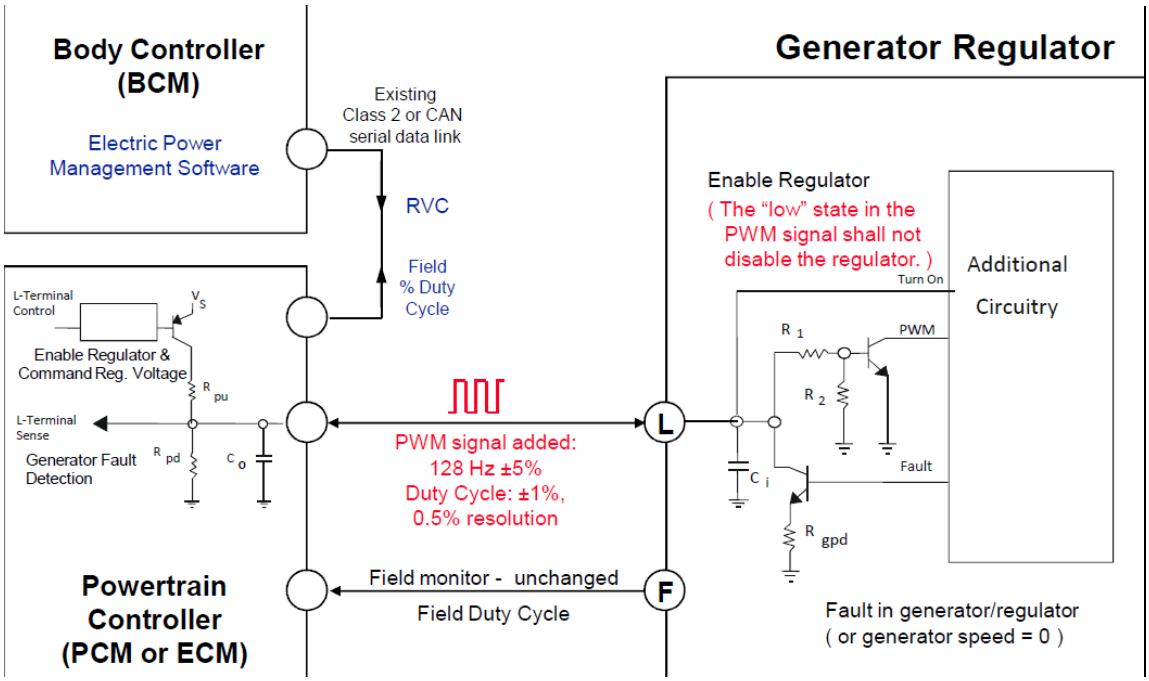



Figure 6. Circuit for L-terminal of RVC.

## 4. Application chart.

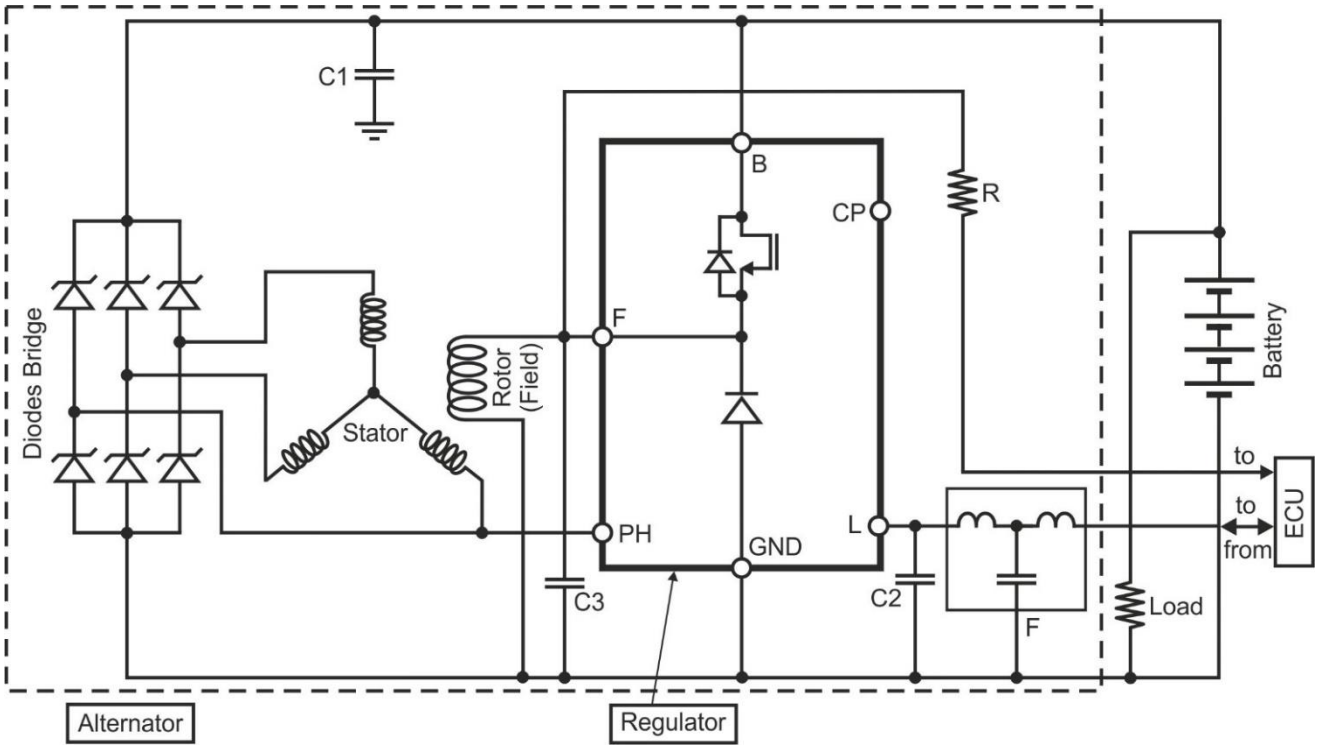



Fig. 7. Application circuit.

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 7. Requirements Levels for the Immunity to Transients on Power Lines.

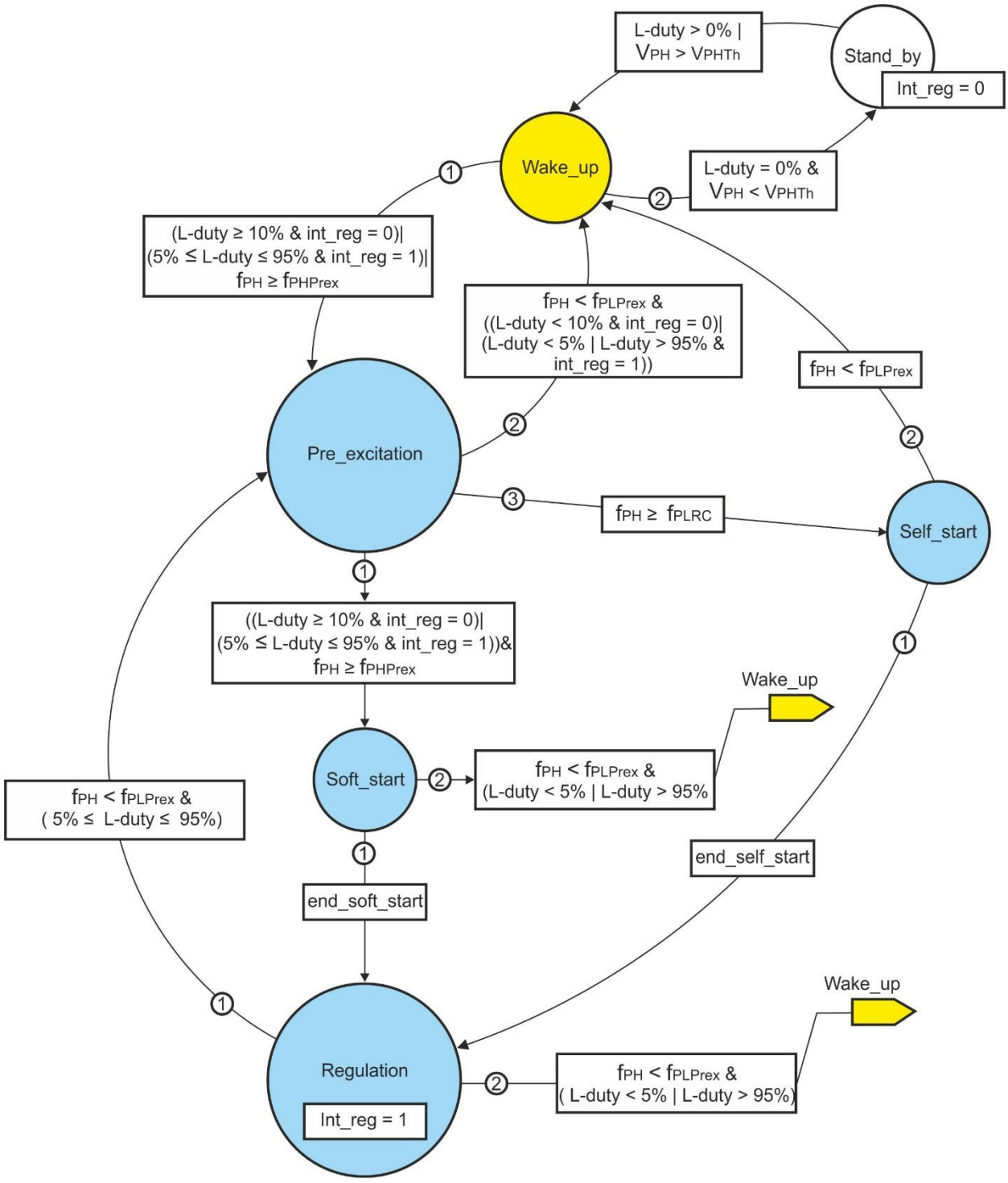
| Pulse Number | Level | Minimum Number of Pulses or Application Time | Pulse Cycle Time | | Comments |
|---|---|---|---|---|---|
| 1 | Us = -150Vpeak | 500 pulses | 0.5s | 5s | One or more functions of the DUT can go beyond specified tolerance as long as all functions return within normal limits after 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 8. 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 6.

**Table 9. 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 10. 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 9) | | |
| | $fL < 1Hz$ & $t_{high\ level} > 1s$ | 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 9) | | |
| | $fL < 1Hz$ & $t_{high\ level} > 1s$ | Field off | Normal regulation, LRC, Default set-point. | Normal regulation, Default set-point |

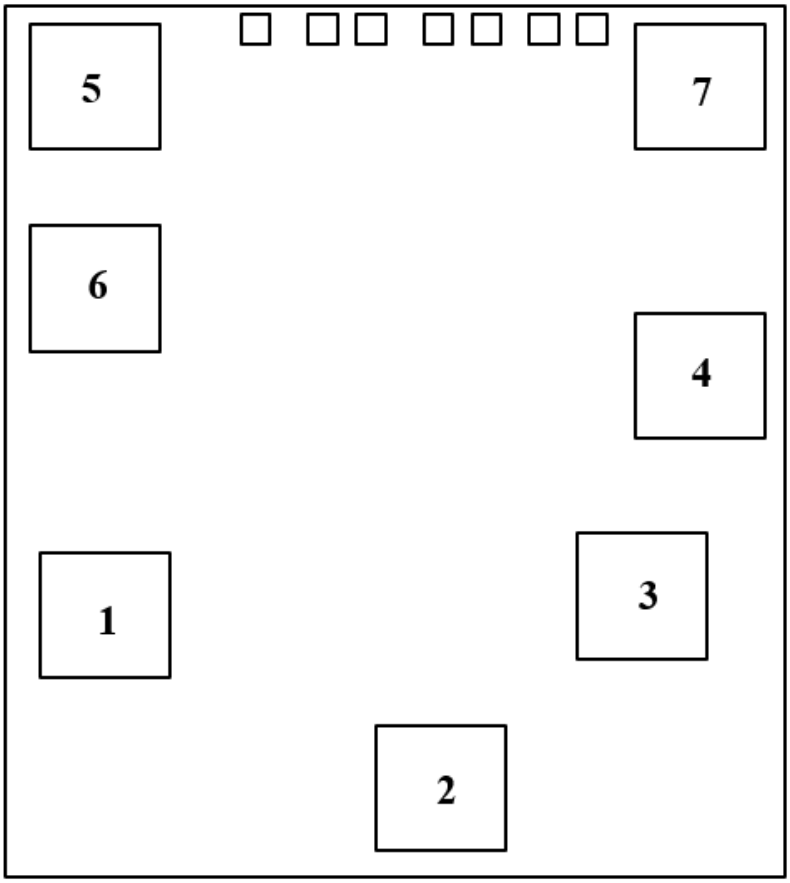
Note:

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**.**

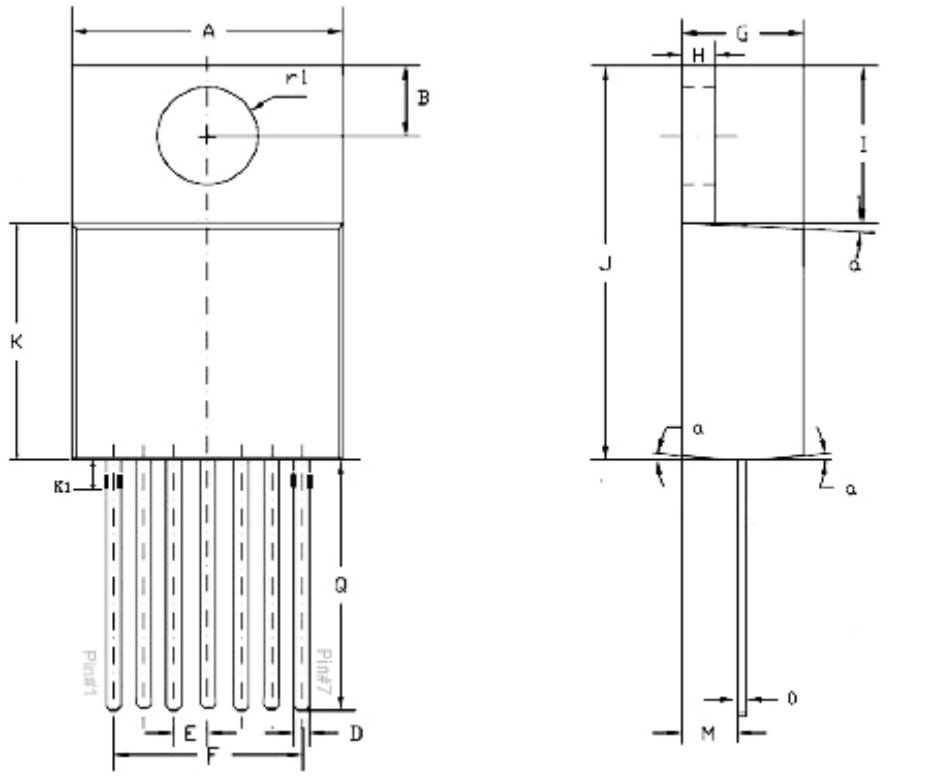
Coordinates of the Pads (“POR” layer)

| 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 – TiW 0.4 um – Au – 0.08 um.
5) Top level metal thickness is 2.7 um typical.
6) Wire thickness should be more 0.2 mm.

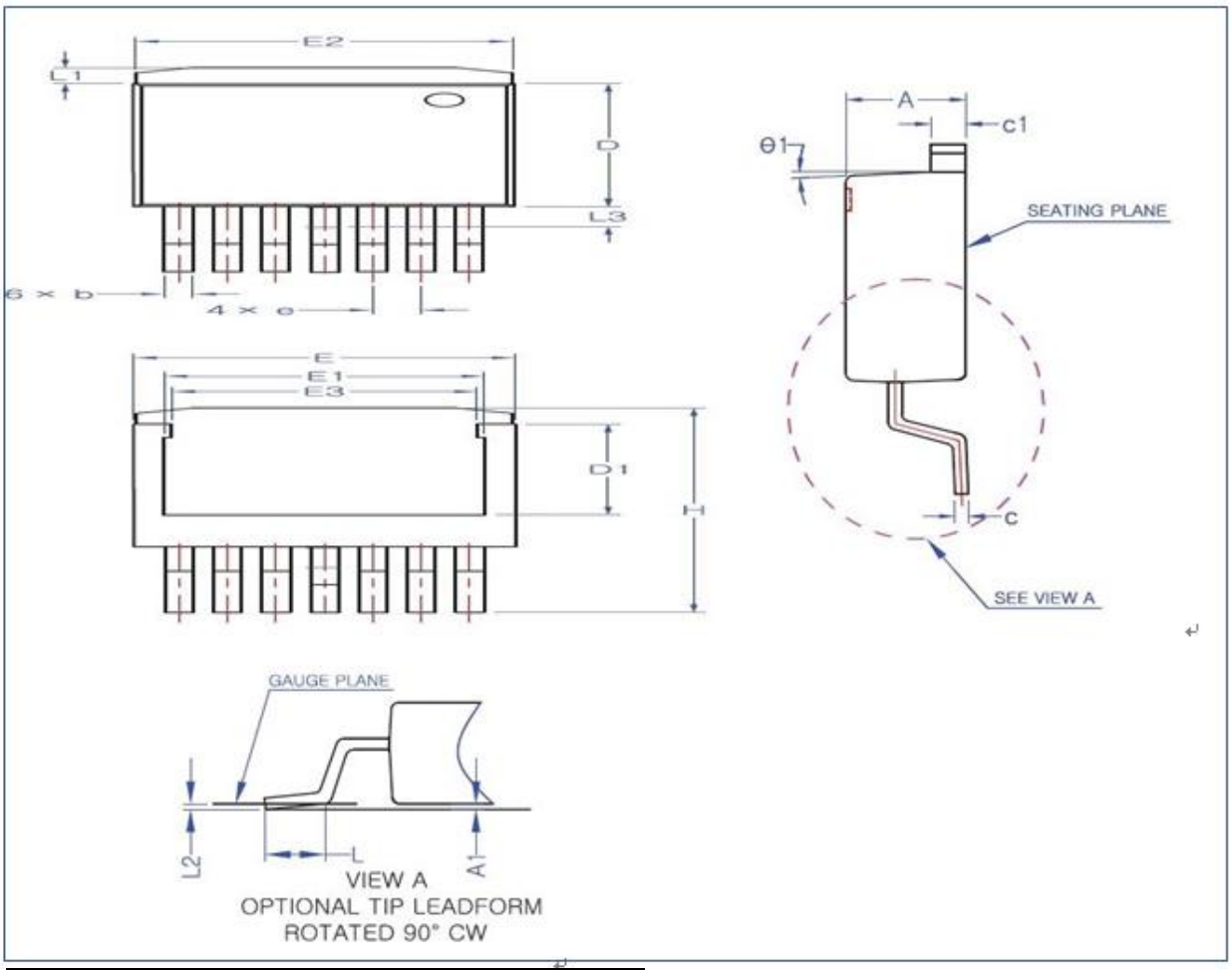
## 8. TO – 220 -7L Package Outline Dimension




Unit: mm

| 符号 | Min | Max | 符号 | Min | Max |
|---|---|---|---|---|---|
| A | 10.0 | 10.5 | J | 14.8 | 15.5 |
| B | 2.65 | 2.85 | K | 8.2 | 8.7 |
| D | 0.65 | 0.75 | K1 | 3.0 | 3.3 |
| E | 1.2 | 1.4 | M | 2.3 | 2.7 |
| F | 7.4 | 7.8 | O | 0.4 | 0.5 |
| G | 4.3 | 4.5 | Q | 9.6 | 10.6 |
| H | 1.3 | 1.4 | r1 | 1.85 | 1.95 |
| I | 6.2 | 6.7 | | | |

## 9. TO-263-7L Package Outline Dimension




| SYMBOL | min | avg | max |
|---|---|---|---|
| A | 4.30 | 4.50 | 4.70 |
| A1 | 0.00 | | 0.25 |
| b | 0.65 | 0.75 | 0.90 |
| c | 0.40 | 0.50 | 0.60 |
| c1 | 1.25 | 1.30 | 1.40 |
| D | 9.00 | 9.20 | 9.40 |
| D1 | 6.70 | 6.80 | 6.90 |
| E | 9.80 | 10.00 | 10.20 |
| E1 | 8.30 | 8.40 | 8.50 |
| E2 | 9.70 | 9.90 | 10.10 |
| E3 | 8.00 | | |
| e | 1.27BSC | | |
| H | 15.00 | 15.30 | 15.60 |
| L | 2.30 | 2.55 | 2.80 |
| L1 | 1.00 | 1.20 | 1.50 |
| L2 | 0.254BSC | | |
| ϕ1 | 3° | | |

**Table 11. 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 |