LC5901S
DATA SHEET Rev.1.5

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CONTENTS

General Description

The LC5901S is a Buck type Single output LED driver IC. This product realizes a high efficiency / high precision LED drive with few add-on parts. It has the protection function which became satisfactory, and complies with the wide LED composition, and copes with analog dimming and PWM dimming.
The LC5901S is an open loop average-mode current control LED driver IC operating in a constant off-time mode(Pulse Ratio Control: PRC). The IC features ±2% current accuracy, tight line and load regulation of the LED current without any need for loop compensation or high-side current sensing and slope compensation.
The LC5901S is available in an 8-pin SOP package that is compact and thin.

Package

SOP8

Features

Converter Block

- Operation：Average Current Mode PRC Control
- Adjustable OFF-time:1.0 to 9.0usec
- External Phase Compensation is unnecessary

LED Controller Block

- PWM dimming
- Analogue dimming
- ±2% LED Current Accuracy

Protection Functions

- LED short Protection Pulse by Pulse
- Current Sense short Protection Auto Restart
- VIN UVLO Auto Restart
- Thermal shutdown(TSD) Auto Restart
- Package : SOP8

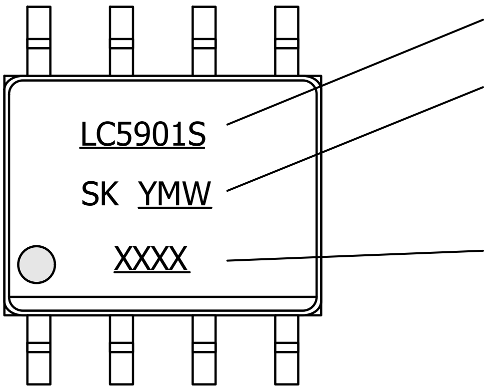
Primary specification

Range of Input Voltage: 7V (MIN)～18V(MAX)
The OFF-time (T_{OFF}) is adjustable from 1.0 to 9.0μsec.

Application

- LED Back-light
- LED Lighting
- LED Light bulb

About Laser Marking



Product’s name

Lot Number
Y= The last digit of the year (0～9)
M= Manufacturing Month (1～9, O=”10”, N=”11”, D=”12”)
W= Manufacturing Week (1～5)

Campany Control Number(4 digit)

1.Absolute maximum ratings

- Certain details refer to the specification sheet of this product.
- The polarity value for current specifies a sink as "+" and a source as "–", referencing the IC.
- Ta=25°C,unless otherwise noted.

Table.1

Characteristic		Terminal	Symbol	Ratings	Units	Remarks
VCC terminal voltage		2−3	V_{CC}	−0.3～+18.0	V	
CS terminal voltage		1−3	V_{CS}	−0.3～+18.0	V	
OUT terminal voltage		4−3	V_{OUT}	−0.3～+18.0	V	
RT terminal voltage		5−3	V_{RT}	−0.3～+3.6	V	
PWM terminal voltage		6−3	V_{PWM}	−0.3～+3.6	V	
UVLO terminal voltage		7−3	V_{UVLO}	−0.3～+3.6	V	
REF terminal voltage		8−3	V_{REF}	−0.3～+3.6	V	
RT terminal sink current		5-3	IRT	±500	μA	
REF terminal sink current		8-3	IREF	±500	μA	
Allowable power dissipation	(1) (2)	—	P_D	1.2	W	
Thermal resistance(junction－lead (#3pin))		—	$\theta_{j\text{-}Pin}$	65	°C /W	
Thermal resistance(junction －ambient temperature)	(2)	—	$\theta_{j\text{-}a}$	95	°C /W	
Junction temperature	(3)	—	T_j	150	°C	
Operating ambient temperature	(1)	—	T_{op}	−40～＋125	°C	
Storage temperature		—	T_{stg}	−40～＋150	°C	

(1) However, it is limited by Junction temperature.
(2) When mounted on a 40×40mm Glass-epoxy board (copper area in a 25×25mm).
(3) Thermal shutdown temperature is approximately 150°C

2. Recommended Operation Conditions

- Recommended Operation Conditions are the required operating conditions to maintain the normal circuit functions described in the electrical characteristics. In actual operation, it should be within these conditions.
- The polarity value for current specifies a sink as "+" and a source as "–" referencing the IC.
- Unless specifically noted, Ta is 25°C

Table.2

Characteristic		Symbol	Ratings		Units	Conditions
			MIN	MAX		
VCC terminal voltage		V_{IN}	8	17	V	
Operating ambient temperature	(4)	T_{OP}	−40	85	°C	

(4) To be used within the allowable package power dissipation characteristics (TBD)

3. Electrical Characteristics

- Certain details refer to the specification sheet of this product.
- The polarity value for current specifies a sink as “+” and a source as “–”, referencing the IC.

3.1 Electrical Characteristics of Control Part (MIC) Unless specifically noted, Ta=25°C、V_{IN}=12V

Table.3

Items		Terminal	Symbol	Ratings			Units	Remarks
				MIN	TYP	MAX		
Operation Start Voltage		2−3	$V_{CC(ON)}$	6.5	7.0	7.5	V	
Operation Stop Voltage		2−3	$V_{CC(OFF)}$	6.0	6.5	7.0	V	
Operation Hysteresis Voltage		2−3	$V_{CC(HYS)}$	—	0.5	—	V	
Supply Current		2−3	$I_{CC(ON)}$	—	1.2	2.0	mA	
Supply Current in No Operation		2−3	$I_{CC(OFF)}$	—	0.35	0.5	mA	V_{UVLO}=0V
OFF Time1		4-3	T_{OFF1}	6.4	8.4	9.8	usec	R_{RT}=80kΩ
OFF Time2		4-3	T_{OFF2}	0.85	1.0	1.2	usec	R_{RT}=10kΩ
Maximum ON Time		4-3	t_{ONMAX}	170	220	280	usec	
Minimum ON Time		4-3	t_{ONMIN}	—	—	1.3	usec	
REF voltage1		8-3	V_{REF1}	0.980	1.0	1.020	V	R_{RT}=12kΩ R_{REF}=10kΩ
REF voltage2		8-3	V_{REF2}	1.764	1.8	1.836	V	R_{RT}=10kΩ R_{REF}=15kΩ
PWM Pin ON Threshold voltage		6-3	$V_{PWM(ON)}$	1.7	2.0	2.5	V	
PWM Pin OFF Threshold voltage		6-3	$V_{PWM(OFF)}$	0.8	1.1	1.9	V	
PWMPin Pull-down Resistance		6-3	R_{PWM}	128	200	280	kΩ	
OUT Pin Output Resistance(source)	(5)	4-3	Ron_H	—	17	—	Ω	
OUT Pin Output Resistance(sink)	(5)	4-3	Ron_L	—	14	—	Ω	
UVLO Pin ON Threshold voltage		7-3	$V_{UVLO(ON)}$	0.75	1.00	1.3	V	
UVLO Pin OFF Threshold voltage		7-3	$V_{UVLO(OFF)}$	0.65	0.85	1.1	V	
UVLO Pin Hysteresis Voltage		7-3	$V_{UVLO(HYS)}$	0.05	0.15	0.25	V	
UVLO Pin Discharge Resistance		7-3	R_{UVLO}	0.5	1.0	1.5	kΩ	
UVLO Pin Discharge-Complete Threshold Voltage		7-3	$V_{UVLO(RST)}$	180	250	320	mV	
OCP Threshold voltage		1-3	V_{OCP}	2.3	2.5	2.7	V	
CS Pin Blanking Time	(5)	1-3	t_{LEB}	—	200	—	nsec	
Thermal-Shutdown Activation Temperature	(5)	—	TSD	—	150	—	°C	
Thermal Shutdown Hysteresis Temperature	(5)	—	$TSD_{(HYS)}$	—	30	—	°C	

(5) Guaranteed by design, not tested.

* The polarity value for current specifies a sink as “+” and a source as “–”, referencing the IC.

3.2 Functional Block Diagram

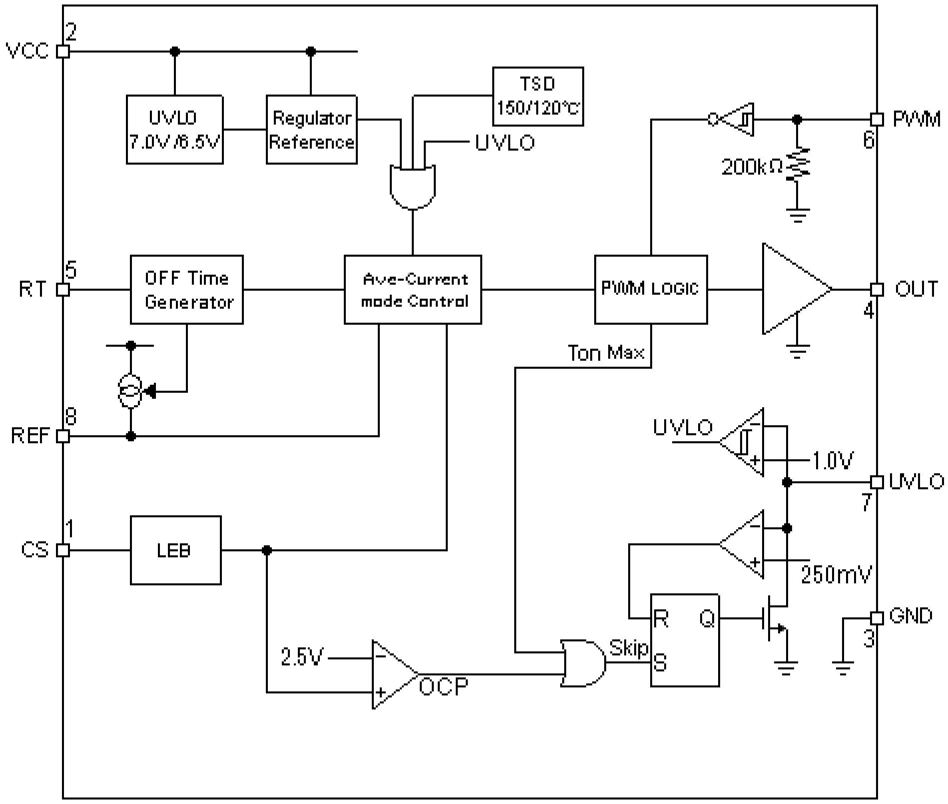


fig.1 Function Block Diagram

4. Pin Assignmennt & Functions

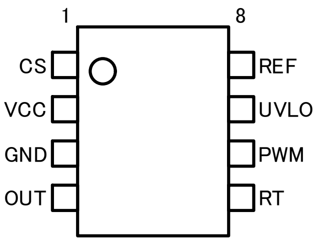


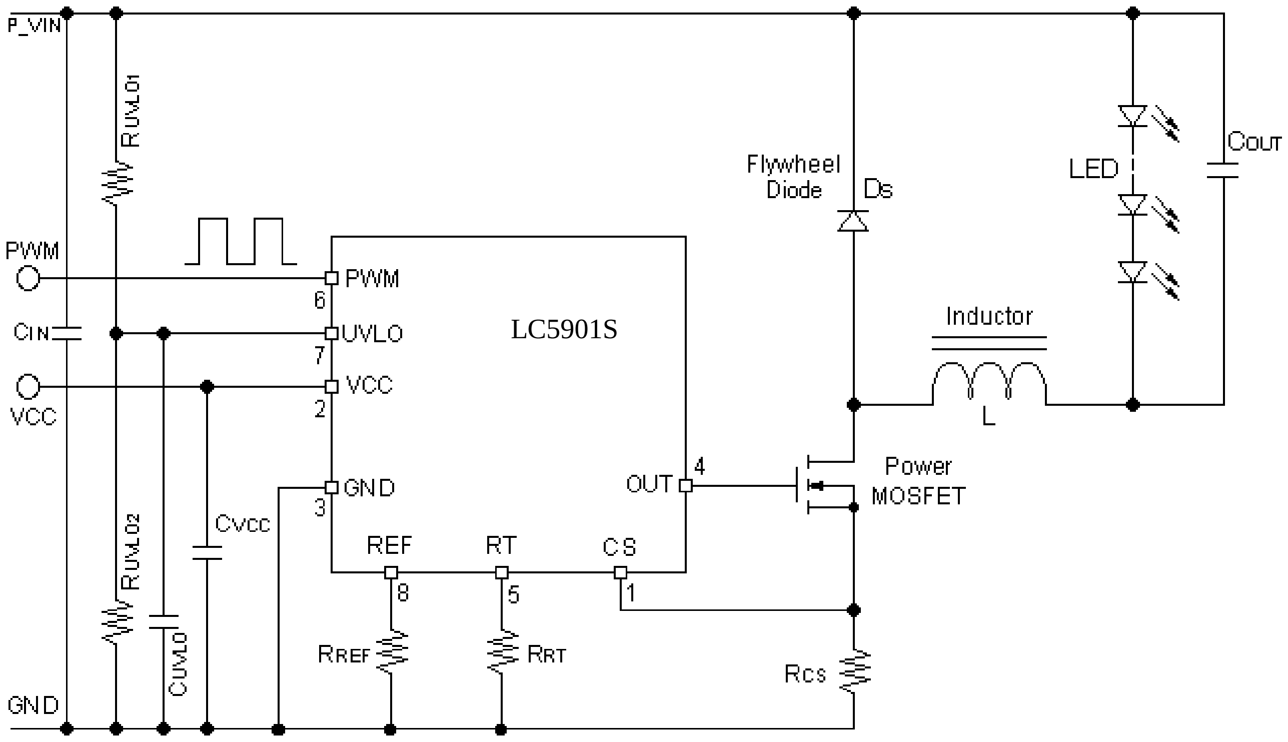
fig.2 Pin Assignment

Table.4

Pin No.	Symbol	Functions
1	CS	LED Current Sense Input.
2	VCC	Supply Input. ・A Input capacitor is connected between VCC and the GND terminal to supply current to the IC. ・Supply input voltage range:8V to 17V.
3	GND	Ground terminal.
4	OUT	Gate drive output of external powerMOSFET.
5	RT	This pin is the terminal to set up OFF-time. A resistor R_{RT} for the adjustment is connected to between the RT terminal and the GND terminal.
6	PWM	PWM Dimming Signal Input. $V_{PWM\ (OFF)}$ <V_{PWM}<2.5V. LC5901S continues off-condition when this pin is held in the one under $V_{PWM\ (OFF)}$.
7	UVLO	Sensing terminal for Under Voltage Lockout. Input the divided voltage of PVIN by Resistance voltage divider circuit.
8	REF	This is the terminal for LED-current control reference setup. A resistor R_{REF} for the adjustment is connected between REF terminal and GND terminal.

5. Basic Circuit Connection

5.1 LC5901S Basic circuit connection



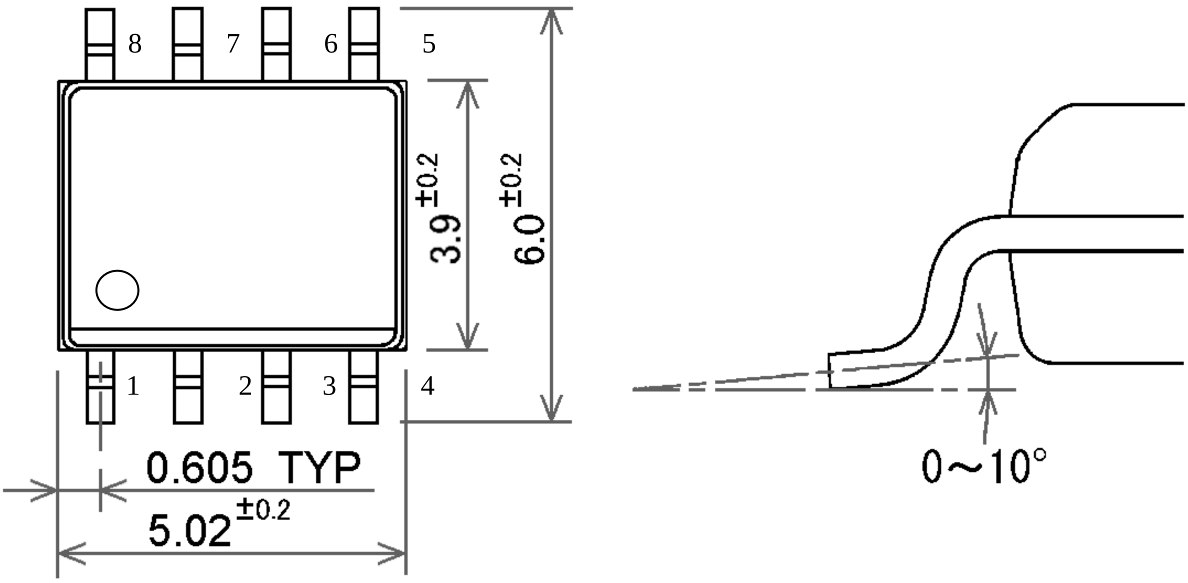
The above shows the basic connection of LC5901S. Refer to a fig21 for the circuit diagram of the demonstration board.

fig.3 LC5901S Basic circuit connection

6. Package Information

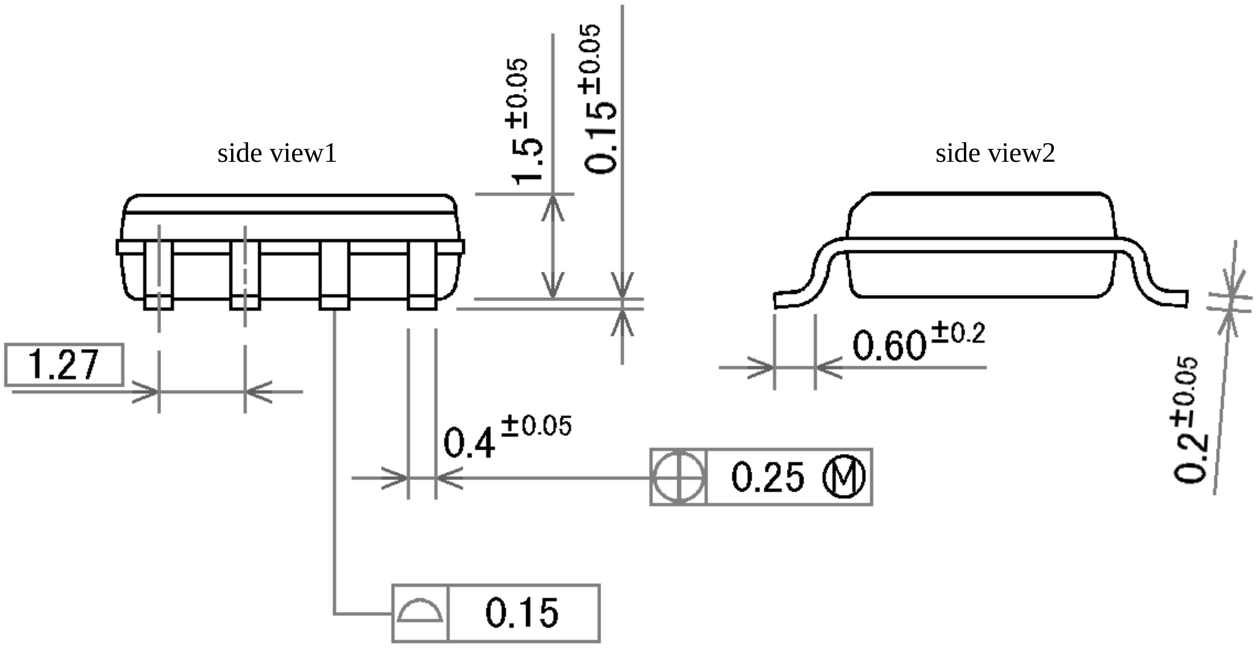
SOP8 Package

Top view



side view1

side view2



NOTES:
1) All dimensions are in Millimeter
2) Drawing is not to scale.

fig.4 SOP8 Package outline Drawing

7. Functional Description

All of the parameter values used in these descriptions are typical values of the electrical characteristics, unless they are specified as minimum or maximum.
With regard to current direction, "+" indicates sink current (toward the IC) and "–" indicates source current (from the IC).

7.1 PRC(Pulse Ratio Control) method

The control of this IC is adopting "PRC method". The "PRC method" of this product, under the condition of fixed "OFF-Period" by external setup resistor R_{RT} , and by controlling "ON-Period", the LED current will be controlled constant current value. It is possible that a system is constructed at a low costs ,because the phase compensation is unnecessary by adopting PRC method. It is possible to set up "OFF-Period" in the optional time by the value of the resistor R_{RT} that is connected to the RT terminal.The "ON-Period" is controlled so that "The average LED current-signal which guessed based on the Switching-current-signal detected in the CS terminal" may become equal to the value of the REF terminal voltage signal set up separately by the external setup resistor R_{REF}.

7.2 The setup of "OFF-Period "

A setup of "OFF-Period" of LC5901S is set up by the value of the external resistor RRT that was connected to between the RT terminal (5 pin) and GND terminal (3 pin). The "OFF-Period tOFF" is able to calculate with an equation (1). The correlation of "OFF-Period" to the resistance value of R_{RT} is shown as the fig 5.

$$t_{OFF}(usec) = \frac{R_{RT}(k\Omega)}{10} \quad \cdots (1)$$

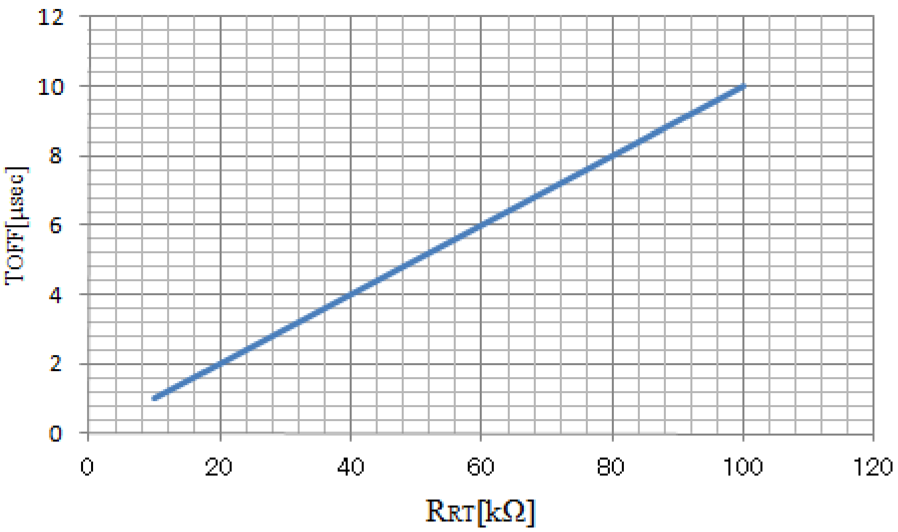


fig.5 the relations of RRT vs. tOFF .

And, the setup of the resistance value of R_{RT} is an important element to decide LED current I_{LED}.

7.2.1 Setup of switching frequency

By the number of series connection of the LED string, the output voltage V_{LED} is expressed with the LED individual $V_F \times N$(number) + CS terminal voltage (V).

Duty $D=V_{LED}/V_{IN}$ ・・・(2)

$T_{ON}=T_{OFF} \times D/(1-D)$ ・・・(3)

$T=T_{ON}+T_{OFF}$ ・・・(4)

$F_{OSC}=1/T$ ・・・(5)

R_{RT} is made 100kΩ. In accordance with the equation(1), T_{OFF}=10μS. The LED individual V_F is made 3.5V(Max), then 14 LED's are made a series connection.

D=49V／110V=0.445

T_{ON}=10μsec×0.445／(1－0.445)=8μsec

T=10μsec＋8μsec=18μsec →F_{OSC}=1／18μsec=55.55kHz

When it makes the graph of this, a fig 6 - a fig 8 are shown.

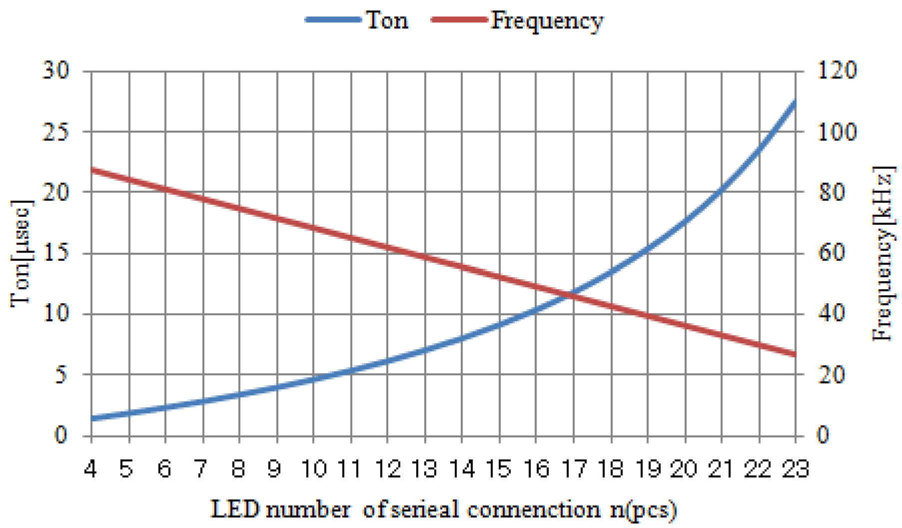


fig.6 R_{RT}=100kΩ,V_{IN}=110VDC condition, Number of LED vs. Ton & Frequency

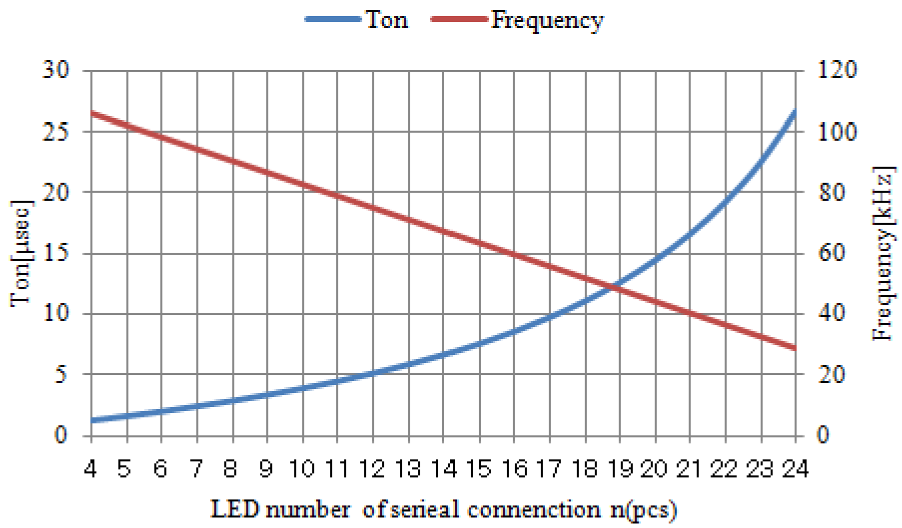


fig.7 R_{RT}=82kΩ,V_{IN}=110VDC condition, Number of LED vs. Ton & Frequency

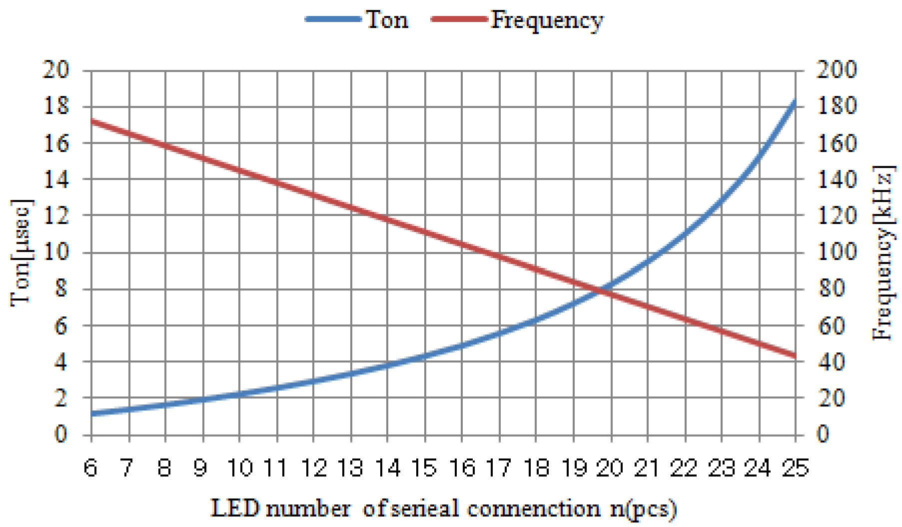


fig.8 R_{RT}=47kΩ, V_{IN}=110VDC condition, Number of LED vs. Ton & Frequency

Like this, switching-frequency rises relatively when a "OFF-Period" is set up short. Moreover, when there are many LED's and V_{LED} is high, it is the character that frequency is decreased because T_{ON} spreads out.

7.3 The Setup of reference voltage(V_{REF})

The reference voltage is set up by the value of the setup resistor R_{REF} that it was connected to between the REF terminal (pin 8) and GND terminal (pin 3) , and the setup resistor R_{RT} that it was connected to between the RT terminal (pin 5) and GND terminal (pin 3) . The reference voltage V_{REF} is able to calculate with an equation (6). The correlation of the reference voltage V_{REF} to the resistance value of R_{REF} is shown as the fig 9. The setup upper limit voltage of the reference voltage is 2.5V.

$$V_{REF}(V) = 1.2\frac{R_{REF}(k\Omega)}{R_{RT}(k\Omega)} \cdots (6)$$

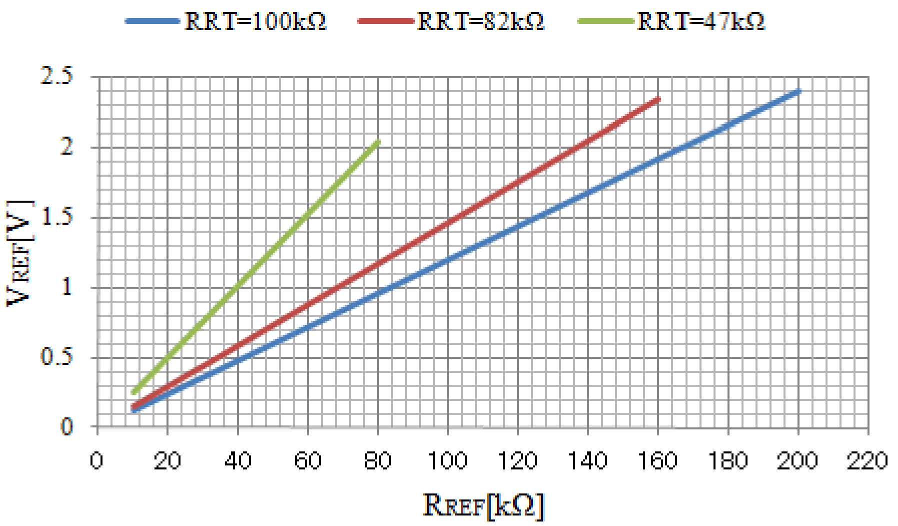


fig.9 the relations of R_{REF} vs. V_{REF} .

Fig 9 is the relations of the reference voltage V_{REF} set up by two resistance of R_{RT} and R_{REF}. By the resistance detector R_{CS} of fig 3, the IC detects the "average LED current" that is flowing to the LED string and the "average LED current" is converted as the voltage signals. It is prediction controlled so that the value of the detected voltage signal may become equal to the reference voltage V_{REF}.

7.4 LED Current Setup

By the output current resistance detector R_{CS},the LED current control detects the LED current I_{LED} when Q1 turns on. It is prediction controlled so that the average value of the detected LED current signal may become equal to the reference voltage V_{REF} voltage set up in advance. The setup of LED current(ILED) is able to calculate with an equation (7). If you want to change LED current value, it can be changed to the optional current value by adjusting the value of the reference voltage setup resistor R_{REF} that is connected to the REF terminal.

(The LED current can be changed by the adjustment of R_{REF} under the condition that the resistance value of R_{CS} is fixed.)

$$I_{LED}(A) = \frac{V_{REF}(V)}{R_{CS}(\Omega)} \quad \cdots (7)$$

When this is graphed, a fig 10 is shown.

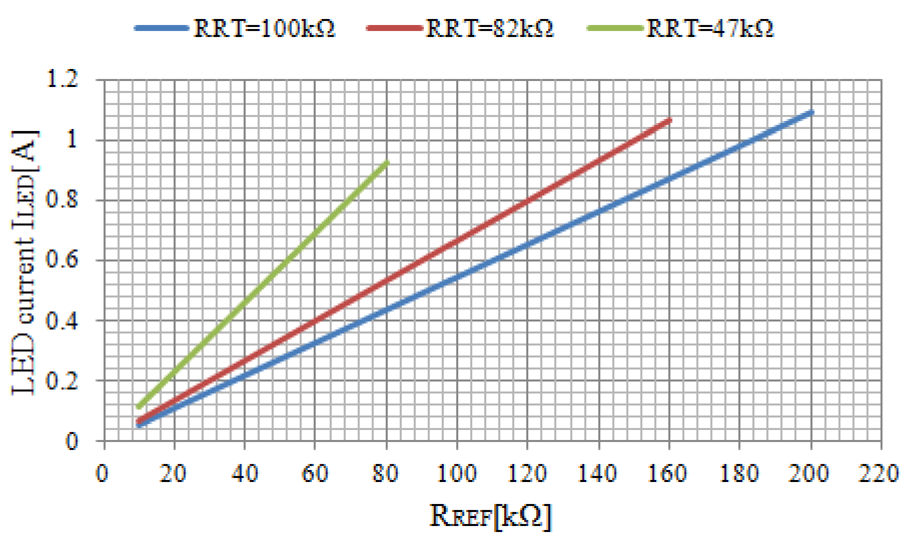


fig.10 V_{IN}=110VDC, R_{REF} vs. I_{LED} @ R_{CS}=2.2Ω, $V_{REF} \leqq 2.5$V

And, in the above relations, when R_{REF} adjusting, it becomes high dissolution that R_{RT} is big, and switching frequency is slow. Though the calculation example of the fig 10 is fixed with R_{CS}=2.2Ω, when this is made 1Ω, the LED current is 2.2 times. Be sure to take a heat-generation of the external powerMOSFET into consideration, adjust I_{LED} by R_{RT} and R_{REF} with the actual working confirmation.

7.5 The function of dimming

7.5.1 PWM dimming

In the PWM terminal, the PWM-dimming-signal which satisfies "ON-threshold voltage $V_{PWM\,(on)}$ =2V" and "OFF-threshold voltage $V_{PWM\,(off)}$ =1.0V" is inputted. (The peak voltage of the drive pulse : 2.5V - 3.3V is recommended.)

The pull-down resistance 200kΩ (typ) is connected between the PWM terminal and the GND terminal.

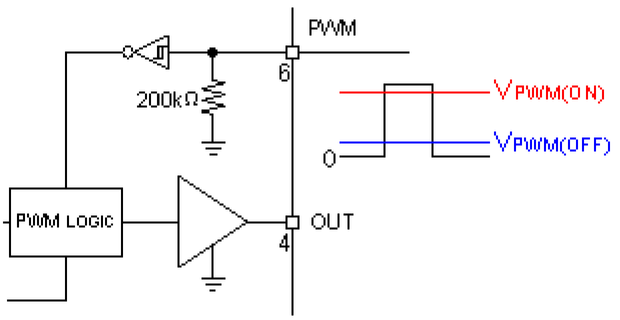


fig.11 The recommendation of the Dimming pulse

7.5.2 Analog dimming

In case of analog dimming , input more than DC 2.5V to the PWM terminal , and make adjustment by your changing R_{REF} connected to the REF terminal.

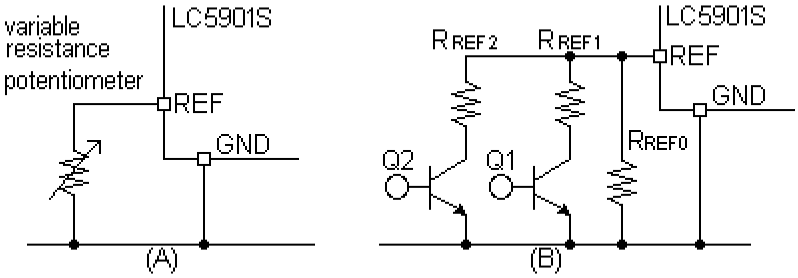


fig.12 the means of the analog dimming .

A fig 12 (A) is a variable method which variable-resistor is used as R_{REF}. A fig 12 (B) is maximum dimming by R_{REF0},and turns on Q1 and Q2 one after another, and composition resistance value is lowered by parallel connection of R_{REF1} and R_{REF2} , and it is the variable method which sets I_{LED} at three steps. Like the fig 10, LED current I_{LED} can be decreased by making R_{REF} small.

7.6 Gate Drive for External PowerMOSFET

The peripheral circuit of the OUT terminal is shown in the fig 13. The OUT terminal is the terminal for the gate drive of the external powerMOSFET.

- Select the PowerMOSFET which a gate-threshold voltage $V_{GS(th)}$ can satisfy the condition of the "$V_{GS(th)} < V_{OUT}$" in all the use temperature ranges.
- By connecting the resistors and diode between the OUT terminal and PowerMOSFET's gate, EMI noise can be controlled. Because turn-on speed and turn-off speed can be reduced.
- To prevent faulty operation by very fast dv/dt in Drain of the PowerMOSFET,connect the discharge resistance of 10kΩ-100kΩ between the gate of the PowerMOSFET and the ground.

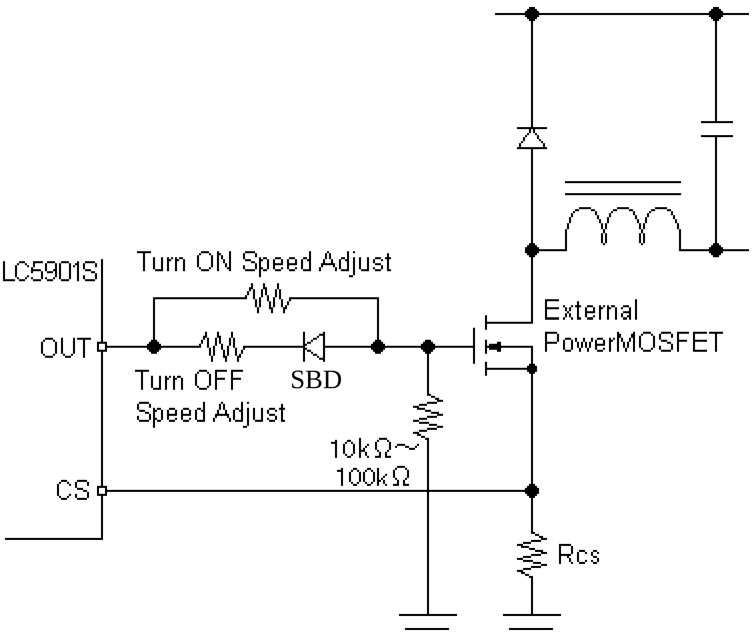


fig.13Gate drive circuit of external PowerMOSFET

As a setup example, in the fig 13, the resistance of "Turn-ON Speed-Adjust" is about 100Ω,and the resistance of "Turn-OFF Speed-Adjust" is about 10Ω. And, connect in series the resistor of "Turn-off Speed-Adjust" to schottky-barrier diode(SBD). It is necessary for SBD's withstands-voltage to be the same as PowerMOSFET's $V_{GSS(Max)}$.

And, the gate drive voltage is not fixed. It is a system that "the OUT-terminal voltage" and "the VCC-terminal voltage" are almost equally. When therefore VCC is 17V, the gate drive voltage is about 17V, too. Select the PowerMOSFET which VGSS(MAx) is ±20V or ±30V . And, in the internal driver output of LC5901S, as for the circuit resistance on the chip…

・Source resistance : 17Ω(Typ)

・Sink resistance : 14Ω(Typ)

This resistance can't be changed. Therefore,like the fig 13,as for the outside adjustment of the switching-speed, insert resistor between the OUT terminal of LC5901S and the gate of the external PowerMOSFET.

7.7 Under Volatege Lock Out(UVLO)

LED power supply voltage decline protection.
A voltage divider circuit divides a main power supply voltage P_VIN for LED. The divided voltage (UVLO signal) is inputted to UVLO terminal. The LC5901S starts a movement when "the UVLO ON-threshold-voltage $V_{UVLO\,(ON)}$ ≧1.0V" is inputted. and, it stops a movement when "the UVLO OFF-threshold-voltage $V_{UVLO(OFF)}$≦ 0.985V" is inputted, even the condition that a "High signal" is inputted to the PWM terminal.
And, when OCP protection and t_{ONMAX} protection activate, in the UVLO terminal, internal reset switch turns on, and discharges electricity in less than 250mV.
By the charge-time-constant of the voltage-dividing-resistor(R_{UVLO1} & R_{UVLO2}) and C_{UVLO}, the movement of LC5901S stops at the period until the UVLO terminal is charged to the voltage which exceeds "the UVLO ON-threshold voltage $V_{UVLO\,(ON)}$".

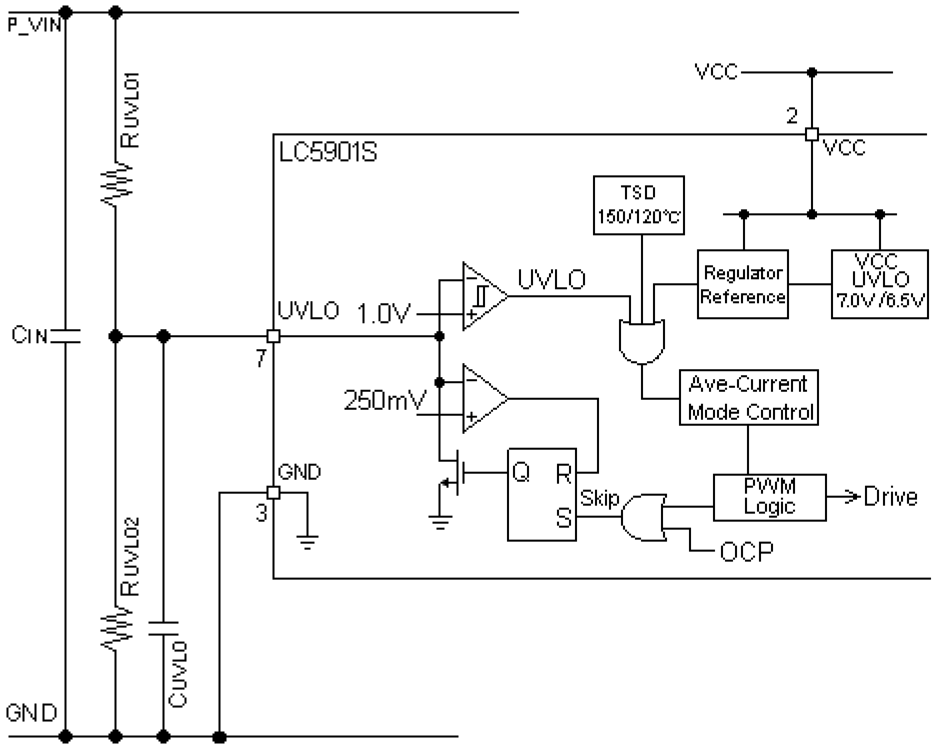


fig 14 . the input of the UVLO terminal .

Aside from P_VIN UVLO, there is VCCUVLO which detects VCC inside the IC. The internal VCCUVLO and the UVLO of UVLO-terminal are "AND" condition. The IC's movement doesn't start when either isn't released.

Be careful of the selection of the resistance value because the detection resistor of UVLO becomes a loss when the P_VIN voltage is high. When R_{UVLO2} in the fig 14 is fixed on 100kΩ, a fig 15 becomes the graph of the UVLO release voltage when the resistance value of R_{UVLO1} of the voltage dividing resistor was made to change.
And, the capacitor C_{UVLO} which is between UVLO terminal and GND is used for the time constant in the SKIP movement.
And,in the protection which UVLO function was used for,there is protection of "Maximum ON time=220μsec".
For example,when the condition that the LED load is opened, ON-period expands to Maximum-ON-time because the CS terminal volatge doesn't reach the reference voltage in control that is the target.
At this moment,the UVLO-terminal voltage is forced discharged, and it becomes protection that is shifted to the SKIP mode (HICCUP mode).

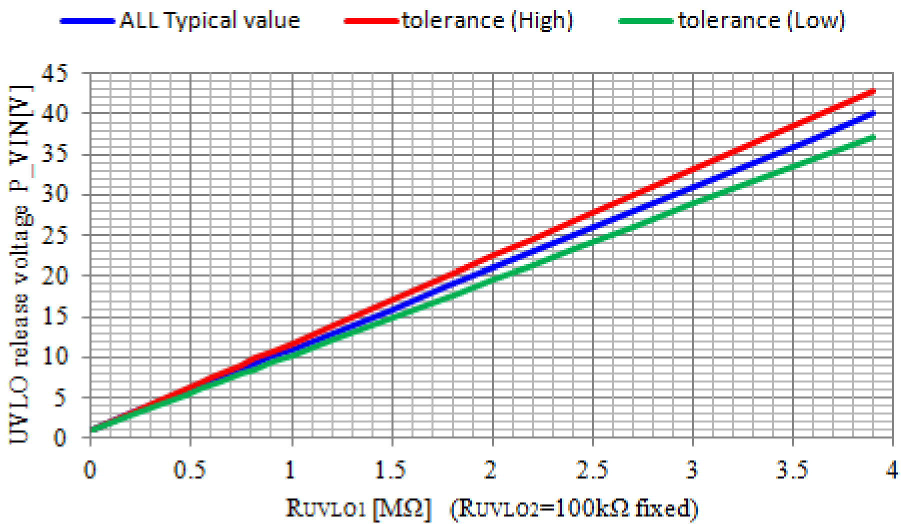


fig.15 Setup example of the UVLO release voltage

In the fig 15,
・All typical value・・・$V_{UVLO(ON)}$=1.00V, R_{UVLO2}=Typ value, R_{UVLO1}=Typ value.
・tolerance(High)・・・$V_{UVLO(ON)}$=1.05V, R_{UVLO2}=－1%, R_{UVLO1}=＋1%
・tolerance(Low)・・・$V_{UVLO(ON)}$=0.95V, R_{UVLO2}=＋1%, R_{UVLO1}=－1%
*For convenience of explanation, the allowable tolerance of the resistance is F (± 1%).
In the regular parts (The allowable tolerance J : ± 5%), as the value of the setup resistance grows big, tolerance width is widened more.
*But, VCC of LC5901S is supplied from other system except for the main circuit P_VIN voltage, and it is the condition of "VIN (on) ≧7V".
*The start voltage $V_{UVLO\ (off)}$ of UVLO is 0.985V.

7.8 Over Current Protection(OCP)

Due to the saturation of inductance, the short circuit, and so on, when the both-ends voltage of the output current detection resistor R_{CS} reaches the condition of the over current protection threshold voltage “V_{OCP}≧2.5V”,then the PowerMOSFET drive signal V_{OUT} shifts to a “Continuous Low level”, and a UVLO discharge switch activates.

The CS terminal voltage reaches 2.5V (typ). (OCP condition occurrence) .

↓①

By the internal discharge impedance 1kΩ,it discharges C_{UVLO} which is the capacitance of the time constant between UVLO and GND.The movement is suspended if a UVLO terminal voltage reaches 0.985V (typ).

↓②

After the movement stops, and C_{UVLO} discharge is continued, if the UVLO terminal voltage reaches to threshold voltage $V_{UVLO\ (RST)}$ = 250mV,then C_{UVLO} discharge stops.

↓③

The C_{UVLO} of the time constant is charged again via the voltage dividing resistor for UVLO setup. The movement starts if the UVLO terminal voltage reaches 1V (typ).

↓

When over-load condition isn't canceled, by repeating ① - ③, the SKIP movement (HICCUP) is continued.

The time interval of SKIP can be adjusted by the capacitance of CUVLO and impedance of the voltage dividing resistor. The main circuit P_VIN is connected to an upside of voltage dividing resistor (R_{UVLO1}). When the voltage of the main circuit P_VIN changes frequently, the time interval of SKIP doesn't sometimes become stable.

Though the Lead-Edge-Blanking (LEB) is built in inside of the CS terminal, when there is superimposition of the large surge-noise on voltage signals of the both-ends of R_{CS}, as the fig 16, use a RC filter together.

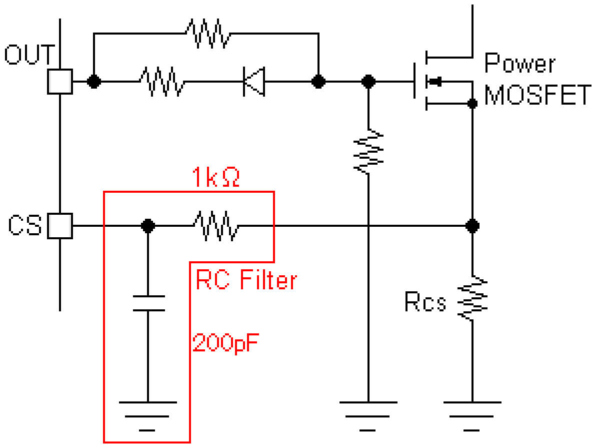


fig.16 A RC filter setup example for the CS terminal .

As the fixed number of RC-filter,when the time constant of C･R is big, control delay grows big and a movement sometimes becomes unstable. Be sure to adjust confirmation by the actual working when you add a RC-filter to cope with the surge-noise.

As for the interval of the SKIP movement (HICCUP), it is based on the character of "discharge and charge" of C_{UVLO}. When over-load condition isn't canceled in the situation which went into the SKIP movement, though a SKIP movement goes on, the interval of the skip depends on a charge by the internal discharge resistance 1kΩ inside of the UVLO terminal,and the composition resistance of "R_{UVLO1} and R_{UVLO2}".

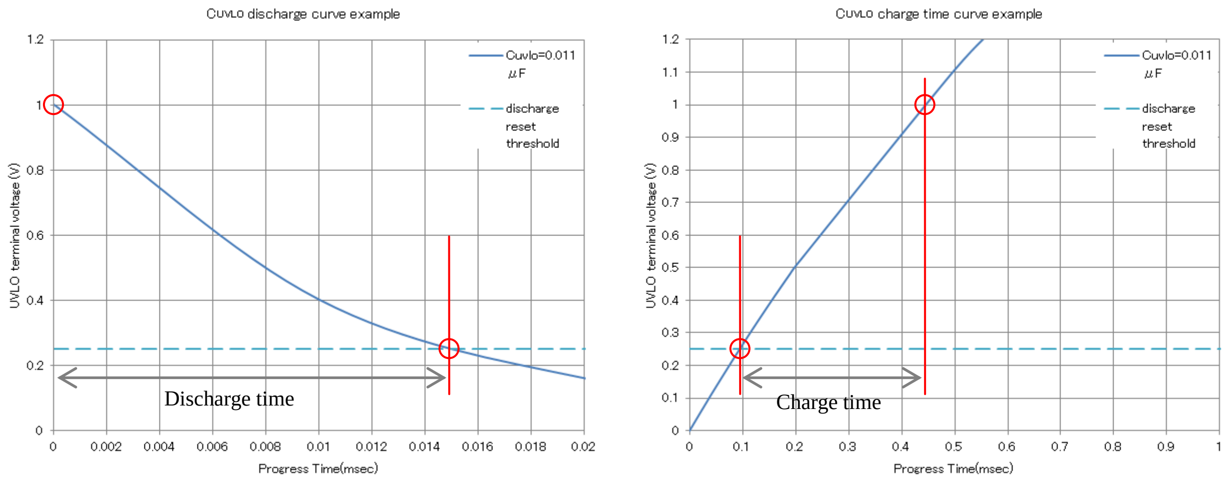
The terminal voltage of C_{UVLO} at the time "t" by discharging $=1V \times e^{-(t/CUVLO \times 1k\Omega)}$ ･･･(8)

*At the V_{UVLO}=1V,though the movement starts after the UVLO release,the moment it started, in case of occurrence of over-current,then the C_{UVLO} is discharged,and it is shifted to the SKIP movement. Therefore, the UVLO terminal voltage is discharged from the condition of 1V, and the discharge is continued until "$V_{UVLO(RST)}$ = 250m V".
After the discharge is finished,by the composition resistance of R_{UVLO1} and R_{UVLO2}, the C_{UVLO} is charged again to V_{UVLO}=1V, this is repeated.
The composition resistance of R_{UVLO1} and R_{UVLO2} : $R_{SUM}=(R_{UVLO1} \times R_{UVLO2})/(R_{UVLO1}+R_{UVLO2})$
The divided voltage by voltage dividing resistor "R_{UVLO1} and R_{UVLO2}": $V_{UVLODIV}=V_{IN} \times R_{UVLO2}/R_{UVLO1}+R_{UVLO2}$

The terminal voltage of C_{UVLO} at the time "t" by charging $=V_{UVLODIV} \times (1-e^{-(t/CUVLO \times RSUM)})$ ･･･(9)

Fig 17 is discharge and charge curve calculation example in setup of C_{UVLO}=0.011μF, in the condition of V_{IN}=110V, R_{UVLO1}=3.6MΩ, R_{UVLO2}=100kΩ.

The interval of SKIP ($T_{INTSKIP}$) : (discharge time of 1V→0.25V) + (charging time of 0.25V→1V).



(A) Discharge time curve (B)Charge time curve

fig.17 discharge and charge curve calculation example

* Adjust C_{UVLO}, and decide a SKIP interval with confirming the heat-generation of each part during the SKIP movement.

7.9 Maximum ON Time Protection

By the factor such as the short circuit of the output current detection resistor R_{CS} and the decline of the LED drive power supply voltage, the Maximum ON-period limitation is set up for the PowerMOSFET drive signal, as a protection when the PowerMOSFET drive signal V_{OUT} continues "High condition".When the ON-period reaches maximum ON-period t_{ONMAX}=220µsec (Typ), the PowerMOSFET drive signal V_{OUT} is shifted to the "Low level" immediately, and a UVLO discharge switch activates. In this case as well, it becomes same control that SKIP on the OCP condition. A fig 18 is a waveform that is Maximum-ON-Time-Protection by LED string opening.

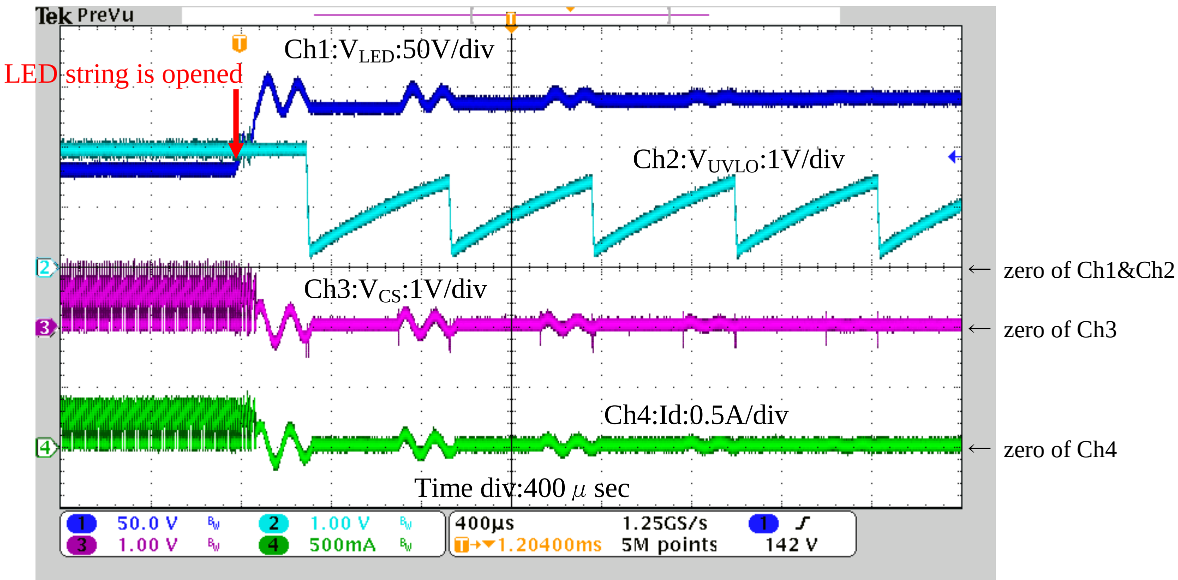


fig.18 the waveform example of the “Maximum-ON-Time-Protection”.

7.10 Thermal Shutdown(TSD)

When temperature of the IC becomes beyond "Thermal-shutdown activation temperature T_J (TSD) typ. = 150℃ ",then the movement is stopped immediately, and the condition of the movement-stop is maintained. It is resumed to the normal operation automatically when temperature of the IC becomes below "T_J (TSD) -T_J (TSD) HYS". T_J (TSD) HYS is set up in about 30℃.

*Precaution
It is a purpose that as for the "Thermal-shutdown", interrupts an IC from the "Thermal-runaway" against the "Heat-Generation" due to increase in a loss by the momentary short circuit and so on. In the condition that continuous-short-circuit and continuous-heat-generation, the movement that is including reliability isn't assured.

8. Precautions for Design

8.1 Peripheral parts

Use each part what conforms to the use condition.

・Input-smoothing-capacitor(Aluminum electrolytic capacitor)

Set up a design margin about the Ripple-current and the withstand-voltage and the life-period properly. Use the aluminum electrolytic capacitor which has high-allowable-ripple-current value and low-impedance character for the "Switching-power-supply".

・Inductor

Set up a design margin properly against rise in temperature by copper loss and the iron loss. Set up a design margin properly against the magnetic saturation.

・Current detection resistor

As the current detection resistor,use the part which is small-parasitic-inductance and satisfies an allowable power loss, because high frequency switching current flows.

8.2 Inductor Design

In the LC5901S,with a calculation example of a stage of design,the setup of inductance which becomes the continuous current mode is recommended. Be careful of this because it is the condition to comply with the control method of this IC.

Because the LC5901S works as buck converter, as a LED drive power supply, it must supply the voltage beyond V_F of LED which becomes a load. Though it is the PRC method of "fixed T_{OFF}", the T_{OFF}-period is set up by the resistance value of the setup resistor R_{RT}. A T_{ON}-period is controlled automatically, it copes with a voltage V_{LED} to supply to the LED string. When the voltage (V_F×n) of the LED string changes,the frequency changes because T_{ON} changes. V_F of LED to use for the calculation must substitute the worst condition value. As the "ON-Duty" of Buck-converter, there are following relations when V_{LED} is supposed to be high enough, and V_F of Flywheel diode DS is omitted…

・1cycle of Switching $T=T_{ON}+T_{OFF}$ ・・・(10)

・$Duty=T_{ON}/T=V_{LED}/V_{IN}$ ・・・(11)

・$T_{ON}=D\times T$ ・・・(12)

・$T=T_{OFF}/(1-D)$ ・・・(13)

・Switching frequency $F_{OSC}=1/T$ ・・・(14)

Here, about the setup of lowered frequency... When a T_{OFF}-period was set up long, be careful that the switching-frequency doesn't move into audible frequency range. For example, when it was set up with T_{OFF}=10µsec, in case of Duty=0.5, 1cycle becomes T=20µsec, therefore the switching-frequency becomes F_{OSC}=50kHz. In case of Duty=0.8,1cycle becomes T=50µsec, the switching-frequency becomes F_{OSC}=20kHz. Because the person who can hear the sound of 20kHz by excellent sense of hearing exists,too. In the worst case, it is recommended that the switching-frequency is set up beyond 30kHz.

Set up the inductance value so that inductor current may become the continuous conduction mode (Continuous Conduction Mode : CCM). As much as possible, the inductance value is to establish big value so that the ripple-current may decrease. Then the LED current I_{LED},and the inductor current become equal mostly. An average of output current I_{LED} is prescribed with $I_{LED\,(AVE)}$. The ripple current is prescribed with ⊿IL. The condition of the CCM movement becomes the following equation.

$I_{LED(AVE)} - \triangle IL / 2 > 0$ ・・・(15)

An increment of inductor-current during the ON-State (T_{ON}-period) of the PowerMOSFET : $\triangle I_{ON}$, The decrement of inductor-current during the OFF-State (T_{OFF}-period) of the PowerMOSFET : $\triangle I_{OFF}$.
The relations with a ripple-current ⊿IL become "$\triangle I_{ON}=\triangle I_{OFF}=\triangle IL$".

Because V_F is small enough to V_{LED}, and it supposes to ignore V_F, As for the $\triangle I_{OFF}$…

$\triangle I_{OFF}=V_{LED}\times T_{OFF} / L$ ・・・(16)

It is shown.

It is supposed here as follows.→Number of serial connection of LED:14pcs ,each V_F:3.5V, As for necessary V_{LED}...
V_{LED}=3.5V×=14pcs=49V,and I_{LED}=0.35A,Input voltage V_{IN}=110V.

A recommendation of the inductor current condition is the continuous conduction mode...
CCM condition : $I_{LED(AVE)} - (\Delta IL / 2) > 0$ ･･･(15／Review)

$I_{LED(AVE)}=0.35A$, in accordance with the equation (15) by the condition of the CCM.
$\Delta IL < 0.7A$
With this, the ripple current of C_{OUT} which is parallel connection with a LED string is big.
So, because "$\Delta IL/Io=0.2 \sim 0.3$" is recommendation of general Buck-type DC/DC converter, the ratio of ΔIL is prescribed with 30% of I_{LED}, ($\Delta IL=0.105A$).
From the calculation example of the fig 6, when the frequency is supposed "$F_{OSC}=55.55kHz$" in case of "$R_{RT}=100k\Omega$", necessary inductance value is calculated as follows...

$L \geqq \{(V_{IN} - V_{LED}) \times V_{LED}\} / (\Delta IL \times V_{IN} \times F_{OSC})$ ･･･(17)

In accordance with the equation (17)...

$L \geqq \{(110V - 49V) \times 49V\} / (0.105A \times 110V \times 55.55kHz) \fallingdotseq 4.7[mH]$

It is calculated like this.
In case of part selection,the inductor must satisfy DC-superimpotion characteristic based on inductance value found by the calculation, and it is asked not to cause magnetic saturation with I_{LED} of the use. And, it is necessary that a heat-generation by DCR of the wire-windings is less than manufacturer guarantee value.

8.3 Flywheel Diode

To revive energy during the OFF-preiod of external PowerMOSFET in a switching-cycle,the Flywheel diode (Flywheel Diode DS of the figure 3) is necessary. Be sure to use the Fast Recovery Diodes / the Ultra Fast Recovery Diodes which has short reverse-recovery-time (Trr). Don't use the Rectifier Diode which the reverse-recovery-time is long. (for example, for rectification of commercial-power-supply.)
Because the big short circuit current flows in recovery-period then diode is giving off heat itself and the normality movement of the main circuit is obstructed, in the worst case,it is sometimes damaged. And, by the use condition, if the reverse-direction-withstand-voltage can be permitted, the Schottky Barrier Diodes is possible to use. As for current of the Flywheel Diode, the peak current of "$I_{LED}+(\Delta IL/2)$" flows in the T_{OFF}-period, and it is repeated in the switching-frequency.

8.4 The Input Smoothing Capacitor(Aluminum electrolytic capacitor)

When the power source supplied to main circuit has an impedance = 0 which is an ideal case, the input current to main circuit is supplied 100% by the power supply and ripple current scarcely flows across the smoothing capacitor, but in specifying the ripple current of the capacitor, the worst condition is considered on the assumption that there exists no ideal power supply.It is assumed that the current is supplied 100% by the worst smoothing capacitor. An input smoothing electrolytic capacitor repeats discharge and charge. A calculation is done with the following process.

$I_{IN(AVE)}=I_{LED} \times D$ ･･･(18) ※D: Duty ($=V_{LED}/V_{IN}$ or $T_{ON}/T_{ON}+T_{OFF}$)、I_{LED}: LED average current

As for the inductor ripple current ΔIL…

$\Delta IL=\{(V_{IN} - V_{LED}) \times T_{ON}\} / L$ ･･･(19)

$ILp'=\{I_{LED}+(\Delta IL/2)\} - I_{IN(AVE)}$ ･･･(20)

$ILb'=\{I_{LED} - (\Delta IL/2)\} - I_{IN(AVE)}$ ･･･(21)

1)Discharge Current

$$I_{CIN\ RIPPLE(DIS)} = \sqrt{\frac{T_{ON} \times (ILp'^2 + ILp' \times ILb' + ILb'^2)}{3 \times T}}$$ ･･･(22)

2)Charge Current

$$I_{CIN\ RIPPLE(CHG)} = \sqrt{(1-D) \times I_{IN(AVE)}^2}$$ ･･･(23)

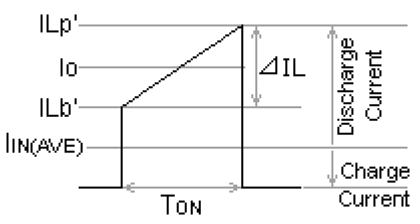


fig.19 Ripple current model in the input smoothing electrolytic capacitor

3)Total ripple current of Input Smoothing Electrolytic Capacitor (I_{CIN})

$$I_{CIN\ RIPPLE} = \sqrt{I_{CIN\ RIPPLE(DIS)}^2 + I_{CIN\ RIPPLE(CHG)}^2} \quad \cdots(24)$$

(Calculation example)
*Conditions:V_{IN}=110VDC、V_{LED}=49V(3.5V×14pcs)、I_{LED}=0.35A、Duty=0.445、R_{RT}=100kΩ(T_{OFF}=10μ sec)、T_{ON}=8μ sec、in case of⊿IL=0.105A, When it is calculated by using the equation (18) – (24)…

・$I_{IN(AVE)}$=0.35A×0.445=0.156A

・ILp'={0.35A＋(0.105A／2)}－0.156A=0.246A

・ILb'={0.35A－(0.105A／2)}－0.156A=0.141A

●Discharge current
・$I_{CIN\ RIPPLE(DIS)}$=SQRT{8μ sec×(0.246A^2＋0.246A×0.141A＋0.141A^2)／3×18μ sec}=0.131A

●Charge current
・$I_{CIN\ RIPPLE(CHG)}$=SQRT{(1-0.445)×0.156A^2}=0.116A

●Total ripple current
$I_{CIN\ RIPPLE}$=SQRT{0.131A^2＋0.116A^2}=0.175$A_{(RMS)}$

When the derating against allowable ripple current of the electrolytic capacitor is set at 90%, and you must select the part, it is necessary that can flow current more than "$I_{CIN\ RIPPLE}$/0.9=0.194A" .

8.5 Current Detection Resistor

As for the current detection resistor can't use a inductive resistor such as a wire-winding type. Unexpected faulty operation sometimes occurs by the surge-voltage in a parasitic inductance element and so on. Use non-inductive resistor such as Metal Plate Resistor /Metal Film Resistor/Carbon Film Resistor. Mount so that lead may become as short as possible in case of Axial lead-type/Radial lead-type .

*Calculation of loss
Conditions:R_{CS}=2.2Ω, R_{RT}=100kΩ, R_{REF}=64.16kΩ, V_{REF}=0.77V(I_{LED}=0.35A)

As for the average loss of the detection resistor R_{CS}, when the current of R_{CS} is prescribed with I_{RCS}…

$I_{RCS}=I_{LED}\times D$ ・・・(25)

$P_{RCS}=I_{RCS}^2\times R_{CS}$ ・・・(26)

I_{RCS}=0.35A×0.445=0.156A
P_{RCS}=0.156A^2×2.2Ω=53.5mW

In case of normal operation,when it thought about only this,1/4W or 1/8W seems to be all right as a power-rating of the 2.2Ω resistor.

But, for some reason, for example, when they became "V_{CS}=2.5V, I_{RCS}=1.136A" continuance under abnormal condition. To prevent "R_{CS} of 2.2Ω" from being damaged on this worst condition...

For example, P_{RCS}'=1.136A^2×2.2Ω=2.839W. ←This electric power is consumed in R_{CS}.
When the derating-factor is supposed 50%, the current detection resistor to stand 5.678W is necessary.
And, it shall not be applied when there is protection cooperation with the fuse and so on separately.

8.6 External PoweMOSFET

Selecting condition :

1)Maximum input voltage of between Drain and Source (V_{DSS})

The voltage of “V_{IN}-V_F (Flywheel Diode)” is inputted between Drain of the PowerMOSFET and Source in the T_{OFF}-period. But, when it considers that the surge-voltage is superimposed on the Vds at the time of turn-OFF. When it is selected in consideration of the safety, as for the Good selection of Vdss, it may be an approximate goal of more than 2 times of V_{IN}.

2) Maximum input voltage of between Gate and Source (V_{GSS})

The gate drive voltage of LC5901S is not fixed, and changes in proportion to the VCC voltage. Pay attention to this point. When it seems that the VCC voltage fluctuates to an upper limit 17V of the recommendation range, select the VGSS specification of 20V-30V. Fundamentally,when stabilized 12V is being inputted to the VCC terminal, the peak value in the pulse wave form of V_{OUT} is about 12V.

3)Others…

In the PowerMOSFET,there is the tendency that the kind of the big internal chip in the big package has low-on-resistance. But, there is the relationship of trade-off. Because, for example the Ciss (capacitance of junction) and so on increases, and big drive current is necessary. When the drive ability of LC5901S is taken into consideration, it seems that the PowerMOSFET of TO-220 classes or smaller size is good selection as a combination.

8.7 The Output Smoothing Capacitor

Decide a C_{OUT} excuse and capacity in accordance with ripple current specifications of the LED string. When the ripple current can be set up greatly, the inductance value of inductor can be set up small, and C_{OUT} capacity can be decreased or deleted. By this setup,the decrease of the scale of the circuit and the cost can be done. When you make the ripple current small, enlarge the inductance value of innductor, and or connect C_{OUT} to the LED string by parallel-connection. When the ripple current is set up small, the heat-generation of LED by a fluctuation of the ripple current can be decreased. And, when a LED string is in the far position from the OUTPUT, the C_{OUT} should be connected near the LED string by parallel-connection, and reduce the ripple current.

The ripple current effective value of output capacitor is calculated from the equation (27).

$$Irms = \frac{\triangle IL}{2\sqrt{3}} \quad -----(27)$$

In case of “$\triangle$IL = 0.5A”,

$$Irms = \frac{0.5}{2\sqrt{3}} \fallingdotseq 0.14A$$

Therefore a capacitor with the allowable ripple current of 0.14A or higher is needed. The output ripple voltage of regulator Vrip is determined by the product of choke current ripple portion ΔIL (= C_{OUT}) discharge and charge current) and output capacitor C_{OUT} equivalent series resistance ESR.

$$Vrip = \triangle IL \cdot Cout_{ESR} \quad -----(28)$$

It is necessary to select a capacitor with low equivalent series resistance ESR in order to lower the output ripple voltage. As for general electrolytic capacitors of same product series, the ESR shall be lower for products of higher capacitance with same breakdown voltage, or of higher breakdown voltage with same capacitance.

When $\triangle$IL = 0.5A, Vrip = 40mV,

$$Cout_{ESR} = 40 \div 0.5 = 80m\Omega$$

A capacitor with ESR of 80mΩ or lower should be selected. Since the ESR varies with temperature and increases at low temperature, it is required to check the ESR at the actual operating temperatures. It is recommended to contact capacitor manufacturers for the ESR value since it is peculiar to every capacitor series.

8.8 PCB Layout & Recommended Land Pattern

8.8.1 Example pattern trace

The pattern traces of the demonstration board of LC5901S is shown in the following.

* Demonstration board (For Evaluation board :t=1.6mm,Single sided PCB,Thickness of Cupper foil=35μm)

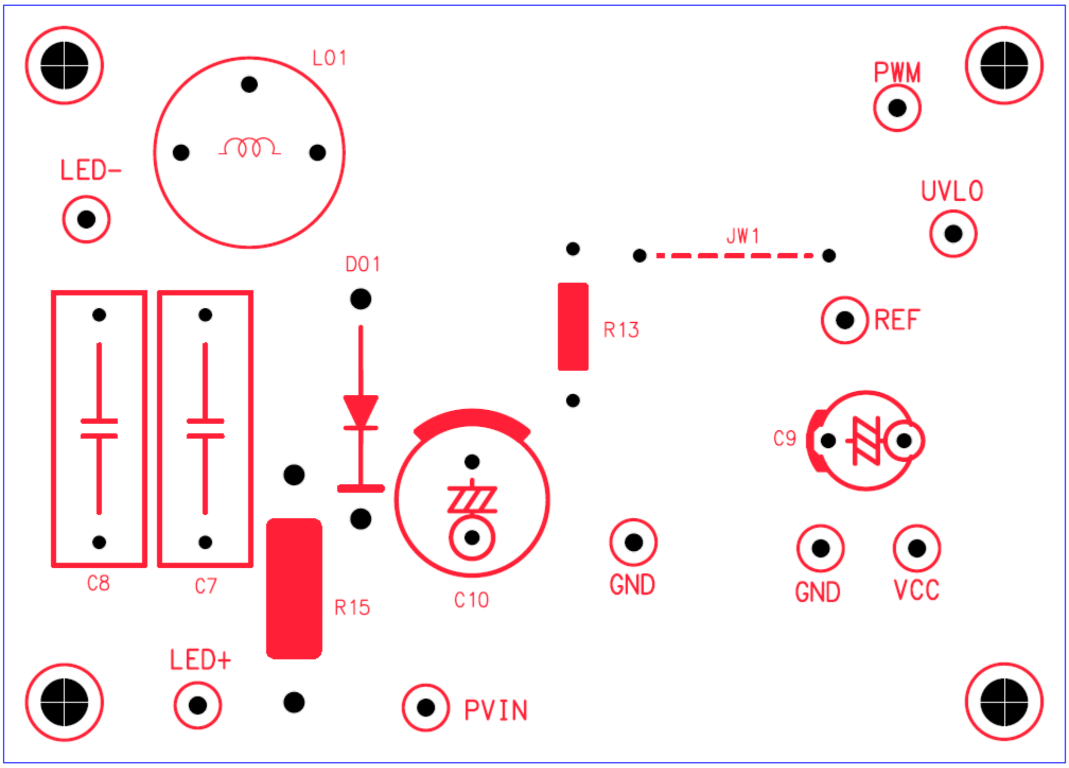


fig.20(A) Top Layer(Silk printing)

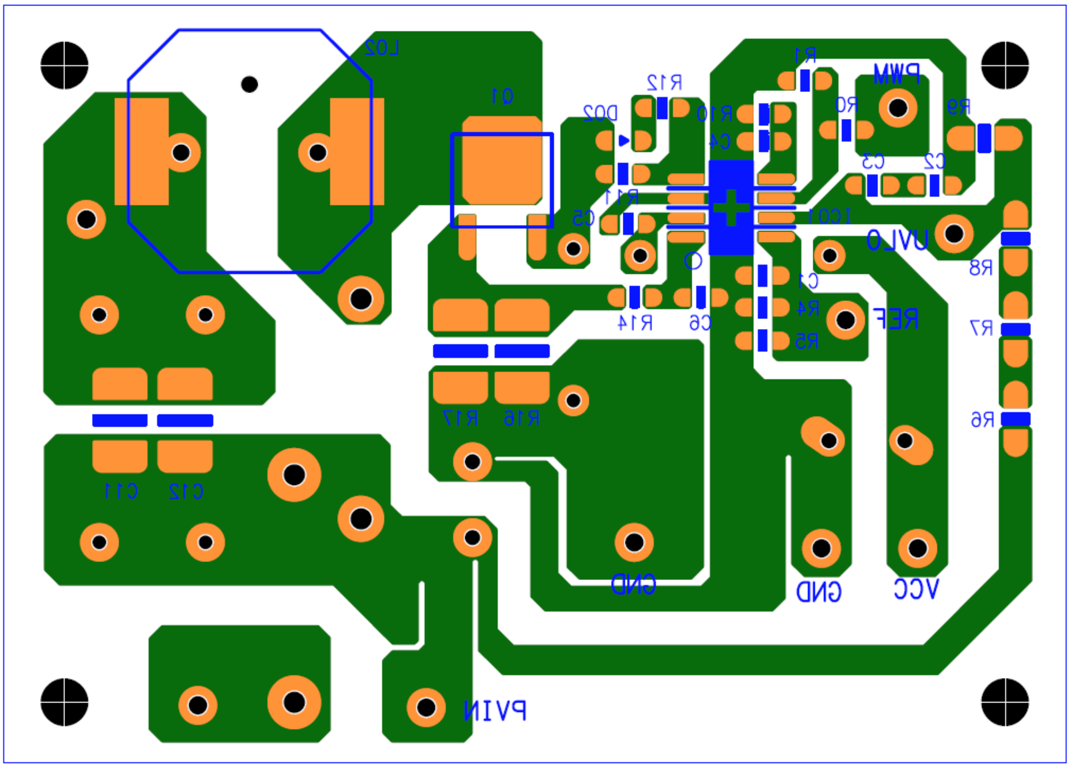
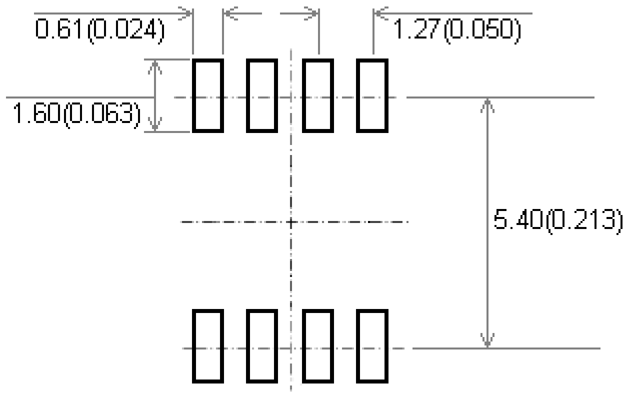


fig.20(B). Bottom Layer(Back side)

* The above circuit board has the possibility that it is amended for the improvement.

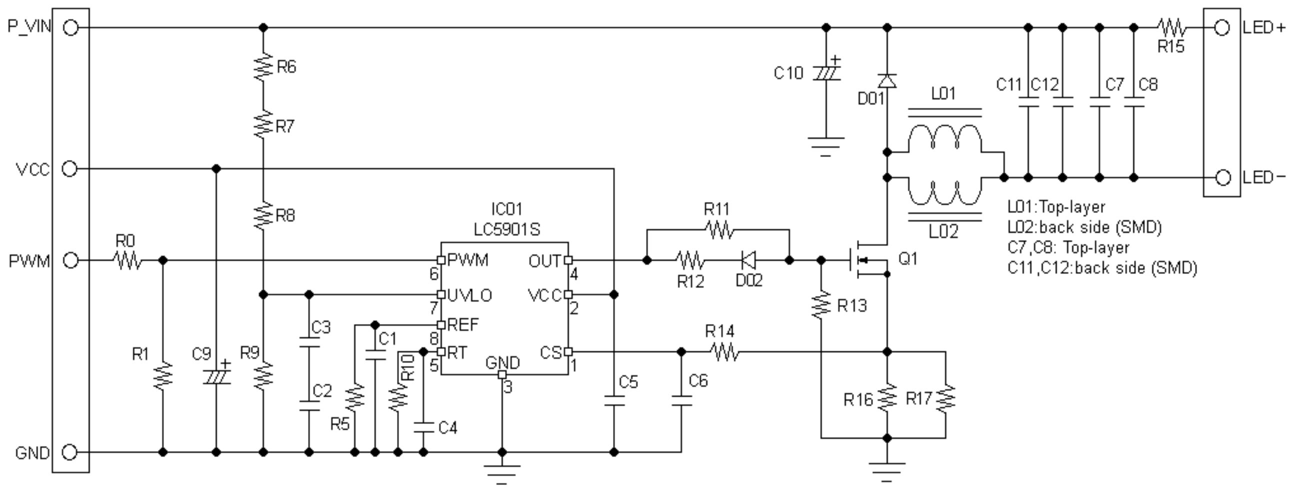


NOTES: For SOP8 package

1) Dimension is in millimeters, dimension in bracket is in inches.
2) Drawing is not to scale.

fig.21 Recommended land pattern(Foot printing)

8.8.2 The circuit diagram of the Demo-board



P_VIN:DC110V, VCC=13V, L01=2.2mH, C1=1nF, C2=C3=22nF, C4=Open, C5=0.22μF, C6=220pF, C7=Open, C8=0.33μF/250V, C9=22μF/25V, C10=10μF/250V, D01=SF28G, D02=1N414WS, IC04=none, Q1=KF9N25D, R1=Open, R2=none, R3=none, R4=none, R5=6.8kΩ, R6=R7=R8=1MΩ, R9=100kΩ, R10=200kΩ, R11=100Ω, R12=10Ω, R13=10kΩ, R14=1kΩ, R15=1Ω/2W, R16=2Ω/2W, R17=Open,

* An optional part is contained because it is the circuit board which evaluates an experiment, too.

fig.22 The circuit diagram of the Demo-board

8.8.3 Attention in circuit board design .

PCB circuit trace design and component layout affect IC functioning during operation. Unless they are proper, malfunction, significant noise, and large power dissipation may occur.
Circuit loop traces flowing high frequency current, as shown in fig.23, should be designed as wide and short as possible to reduce trace impedance.
In addition, earth ground traces affect radiation noise, and thusshould be designed as wide and short as possible.
Switching mode power supplies consist of current traces with high frequency and high voltage, and thus trace design and component layout should be done in compliance with all safety guidelines.
Furthermore, because an integrated power MOSFET is being used as the switching device, take account of the positive thermal coefficient of $R_{DS(ON)}$ for thermal design.

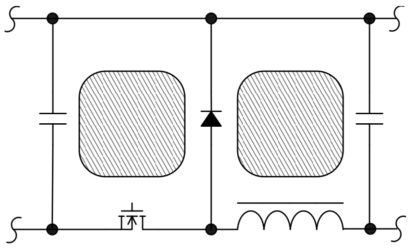


fig.23 High frequency current loops（hatched portion）

IC peripheral circuit

(1) Main Circuit Traces
Main circuit traces carry the switching current; therefore, widen and shorten them as much as possible.
The loop formed with C_{IN}, V_{IN} pin, and GND pin should be small in order to reduce the inductances of the traces against high frequency current.

(2) Traces around GND pin
Main circuit GND and Control circuit GND should be connected to the vicinity of GND pin with dedicated traces respectively, in order to avoid interference of the switching current with the control circuit.

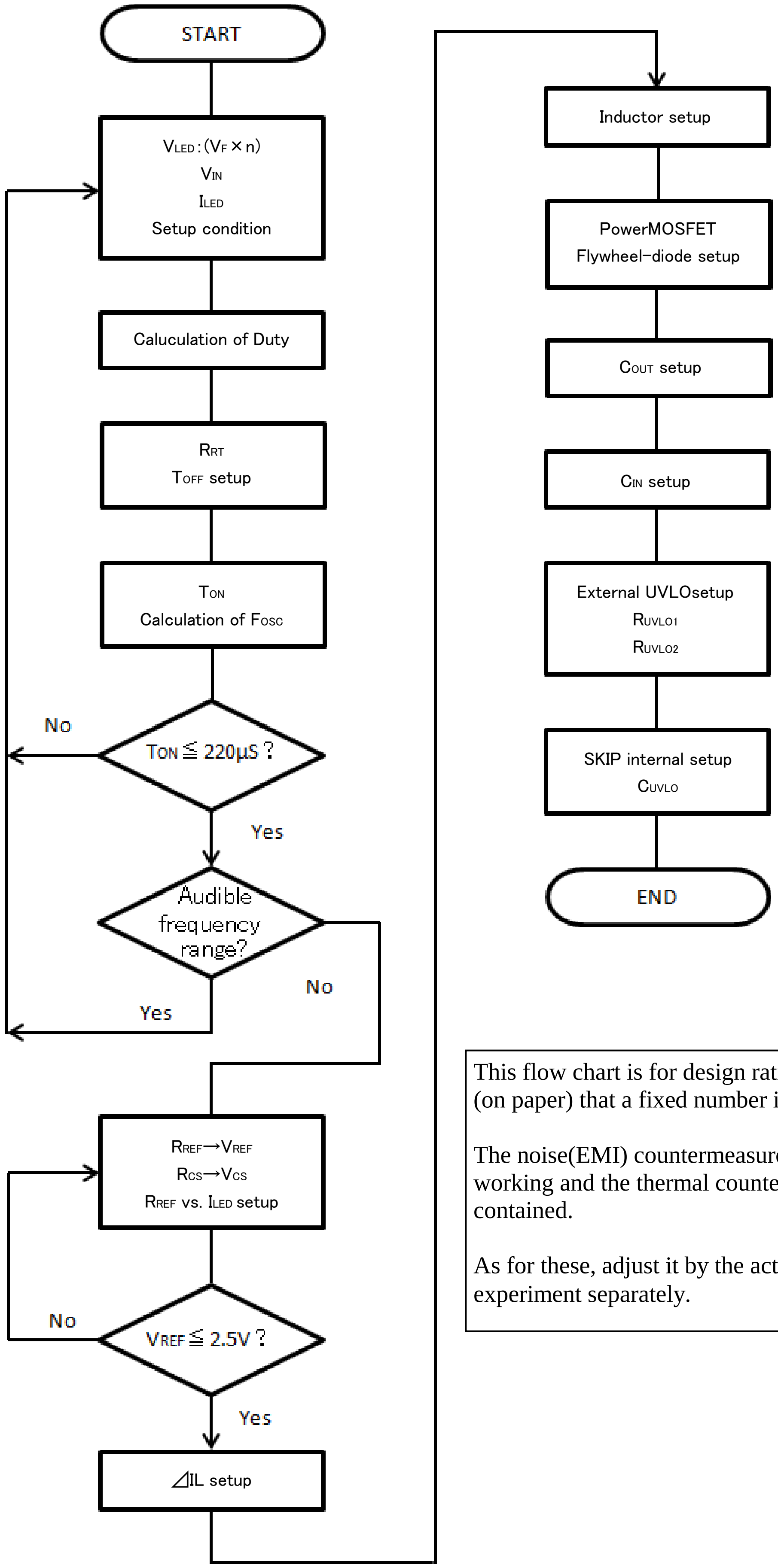
(3) Traces around the current detection resistor, R_{CS}
To decrease noise in the current detection, wire the neighborhood of RCS for the pattern of RCS connected with the CS terminal and the CS terminal by the special pattern.

(4) Peripheral components
Connect the T_{OFF} setup resistor R_{RT} and the reference voltage setup resistor R_{REF} near the GND terminal in the same way, too. Be careful that the GND-pattern where the main-circuit-current flows, and a signal GND-pattern don't become the common-impedance.

(5) When C_{OUT} is used, it should be connected close to LED string.

* As for the GND pattern, be careful that routes for the Main-circuit(switching current flows), and the routes for the small-signal don’t become common impedance.

9. Design flow chart



This flow chart is for design rationale (on paper) that a fixed number is only set up.

The noise(EMI) countermeasure in the actual working and the thermal countermeasure aren't contained.

As for these, adjust it by the actual working experiment separately.

10. Packing specifications

10.1 Taping & Reel outline

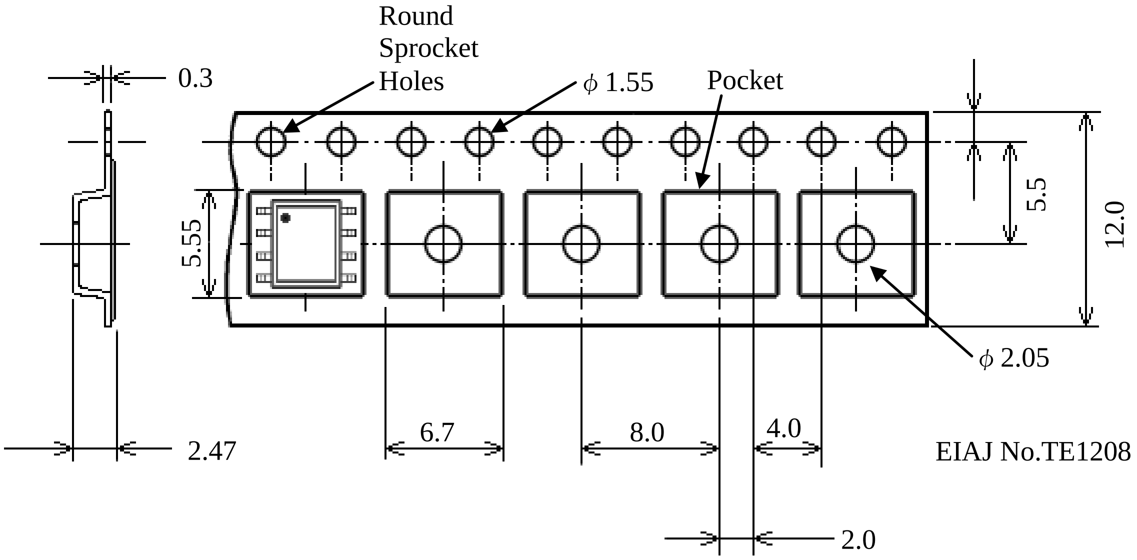


fig. 24 Taping outline

Notes:
1) All dimensions in millimeters
2) Surface resistance：under $10^9\,\Omega$
3) Drawing is not to scale

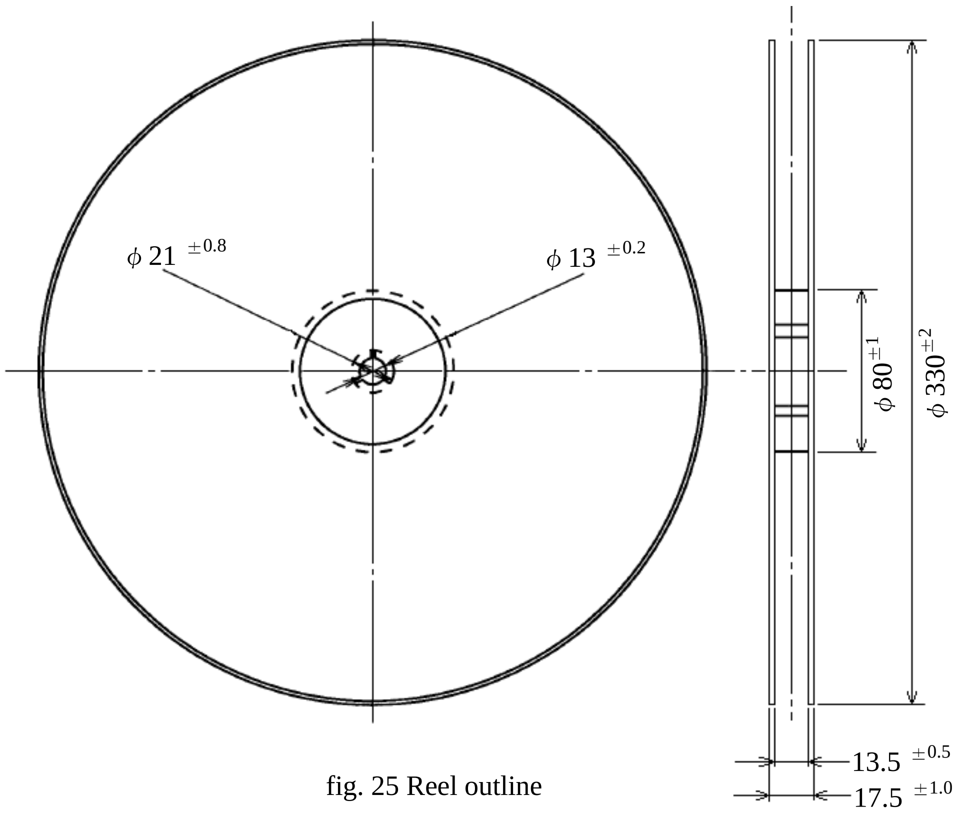


fig. 25 Reel outline

Notes:
1) All dimensions in millimeters
2) Drawing is not to scale.

EIAJ No.RRM-12DC

Quantity
4000pcs／reel

11.Typical characteristics

Conditions : V_{CC}=12V,R_{RT}=10kΩ, R_{REF}=5kΩ, Ta=25℃

8.1 V_{CC} vs. $I_{CC(ON)}$

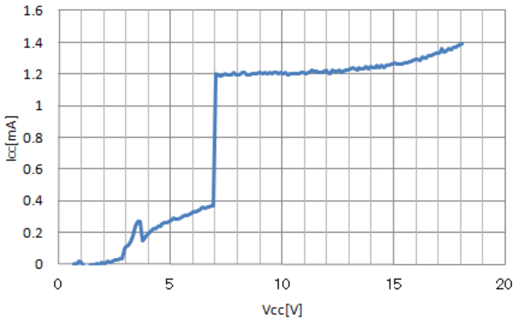


fig.26

8.2 V_{CC} vs. $I_{CC(OFF)}$

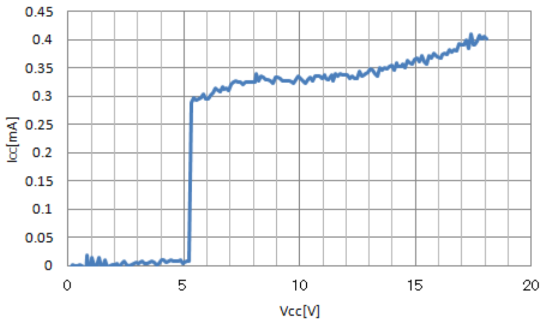


fig.27

8.3 V_{PWM} vs. V_{OUT}

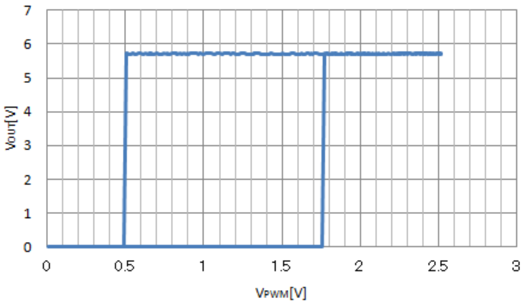


fig.28

8.4 V_{UVLO} vs. V_{REF}

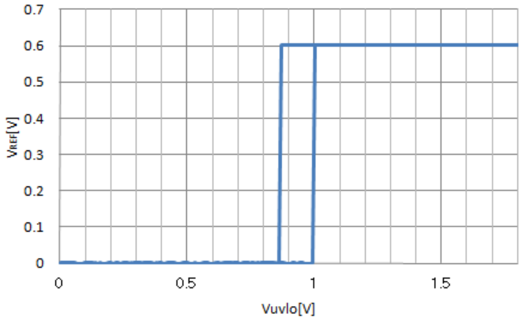


fig.29

8.5 V_{UVLO} vs. I_{UVLO}

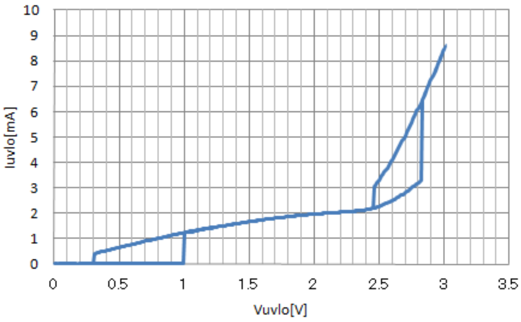


fig.30

8.6 V_{CS} vs. I_{UVLO} (V_{CS}=2.5V→OCP/HICCUP)

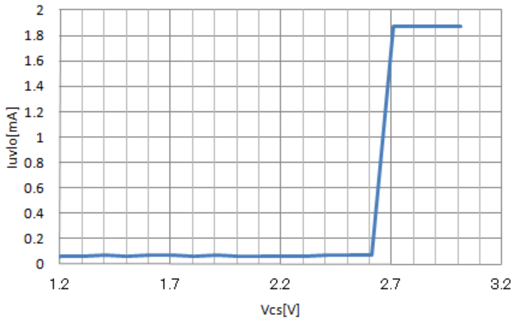


fig.31

8.7 Ta vs. V_{OUT} (Thermal Shut-down Activation)

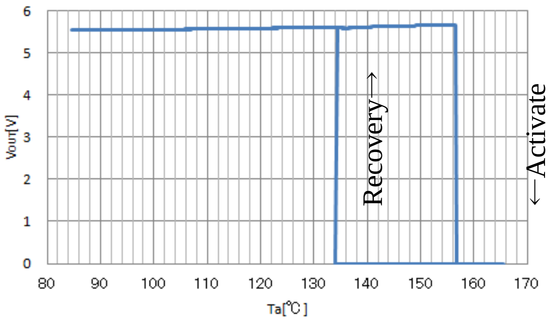


fig.32

8.8 Ta vs.Ton(Min)

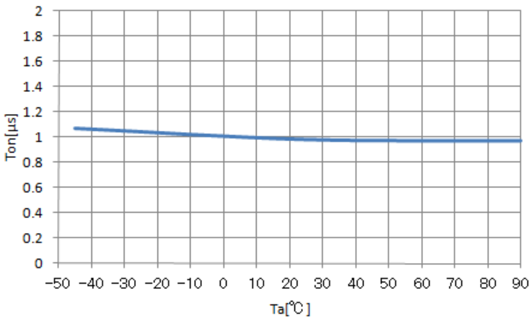


fig.33

8.9 Ta vs. Ton(Max)

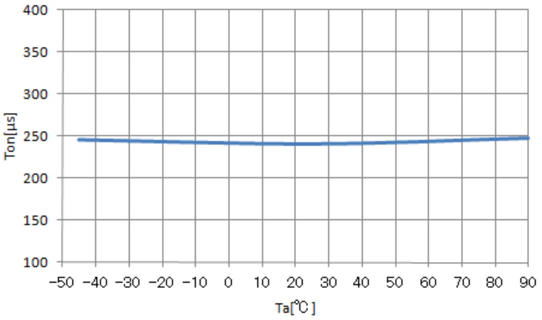


fig.34

8.10 Ta vs. T_{OFF} (R_{RT}=10kΩ)

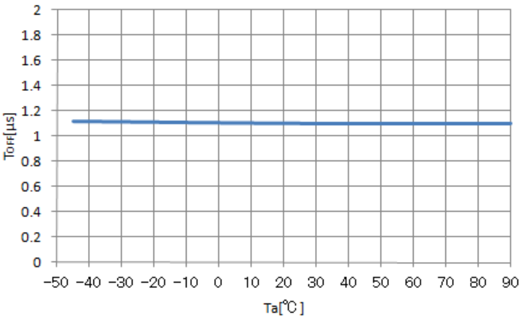


fig.35

8.11 Ta vs. T_{OFF}(R_{RT}=80kΩ)

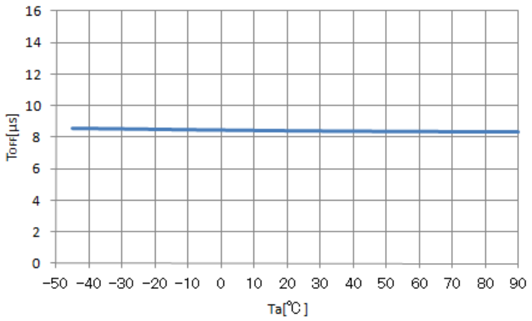


fig.36

8.12 Ta vs.V_{REF}(R_{REF}=5kΩ)

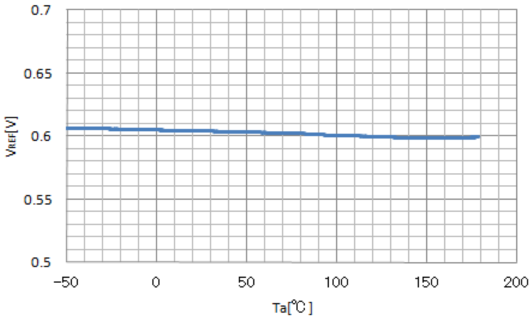


fig.37

8.13 Ta vs. PWM Pin Pull-down Resistance

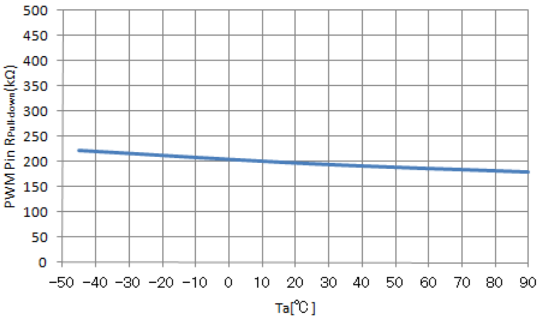


fig.38

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