White LED Driver (Charge Pump with Current Source)

General Description

The RT9360 is a compact, high efficient and high integration charge pump with current matched white LED driver. It can support 1 to 4 White LED's and optimized for Li-Ion battery applications. The four WLEDs current are matched for consistent brightness. User can control WLED on/off via three programming bits. The every WLED channel can support up to 30mA current.

Features

- **Very High Efficiency Over 90% of Battery Life**
- **Support up to 4 WLEDs**
- **Soft Start Function**
- **Short Circuit Protection**
- **Three Charge Pump Mode : X1, X1.5, X2**
- **250kHz/1MHz Fixed Frequency Oscillator**
- **RoHS Compliant and 100% Lead (Pb)-Free**

Ordering Information

RT9360A/B□□

- Package Type
  QV : VQFN-16L 4x4 (V-Type)
- Operating Temperature Range
  C : Commercial Standard
  P : Pb Free with Commercial Standard
- A : 250kHz
  B : 1MHz

Note :

RichTek Pb-free products are :

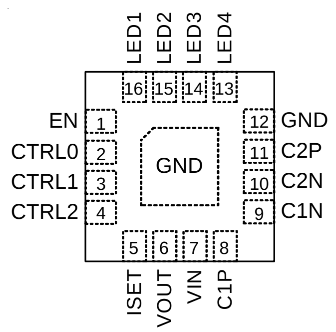
- RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- Suitable for use in SnPb or Pb-free soldering processes.
- 100% matte tin (Sn) plating.

Applications

- Mobile phone
- White LED Backlighting
- Camera Flash LED lighting

Pin Configurations

(TOP VIEW)



VQFN-16L 4x4

Marking Information

For marking information, contact our sales representative directly or through a RichTek distributor located in your area, otherwise visit our website for detail.

Typical Application Circuit

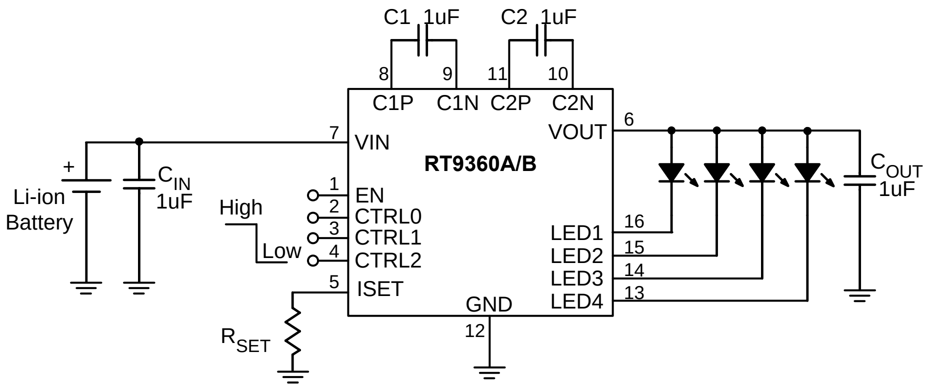


Figure 1. For 4-WLEDs Application Circuit

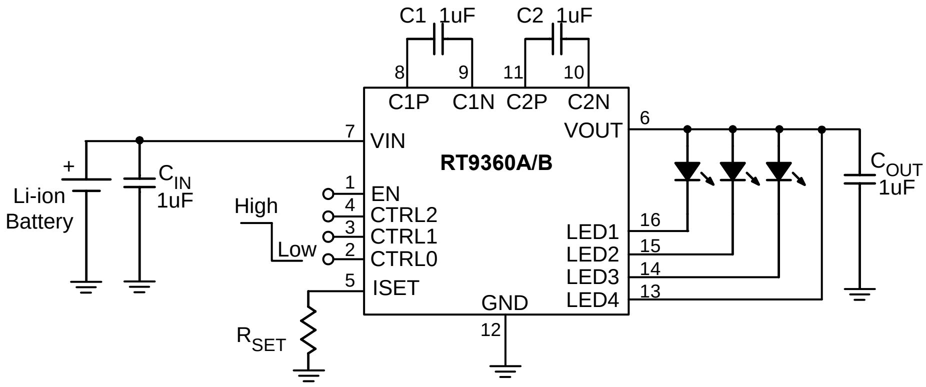


Figure 2. For 3-WLEDs Application Circuit

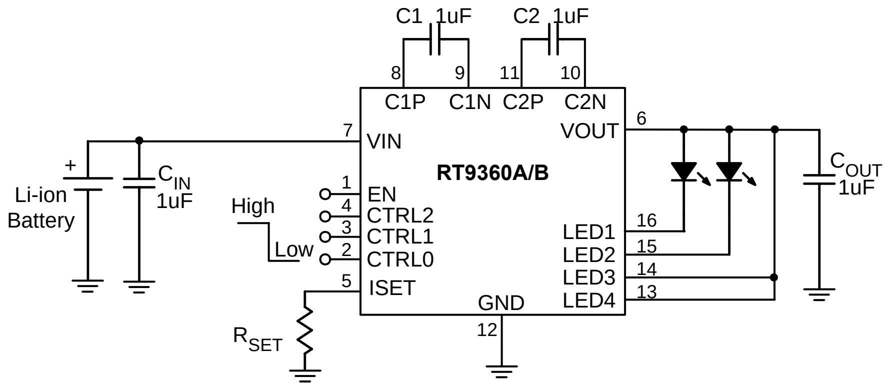


Figure 3. For 2-WLEDs Application Circuit

Functional Pin Description

Pin Number	Pin Name	Pin Function
1	EN	Chip Enable (Active High). Note that this pin is high impedance. There should be a pull low 100kΩ resistor connected to GND when the control signal is floating.
2	CTRL0	Output Control Bit 0. (See Table 1)
3	CTRL1	Output Control Bit 1. (See Table 1)
4	CTRL2	Output Control Bit 2. (See Table 1)
5	ISET	LED current is set by the value of the resistor R_{SET} connected from the ISET pin to ground. Do not short the ISET pin. V_{ISET} is typically 1.1V.
6	VOUT	Output Voltage Source for connection to the LED anodes.
7	VIN	Power Input Voltage
8	C1P	Positive Terminal of Bucket Capacitor 1
9	C1N	Negative Terminal of Bucket Capacitor 1
10	C2N	Negative Terminal of Bucket Capacitor 2
11	C2P	Positive Terminal of Bucket Capacitor 2
12	GND	Ground.
13 to 16	LED1 to 4	Current Sink for LED. (If not in use, pin should be connected to V_{OUT})
Exposed Pad	GND	Exposed pad should be soldered to PCB board and connected to GND.

Function Block Diagram

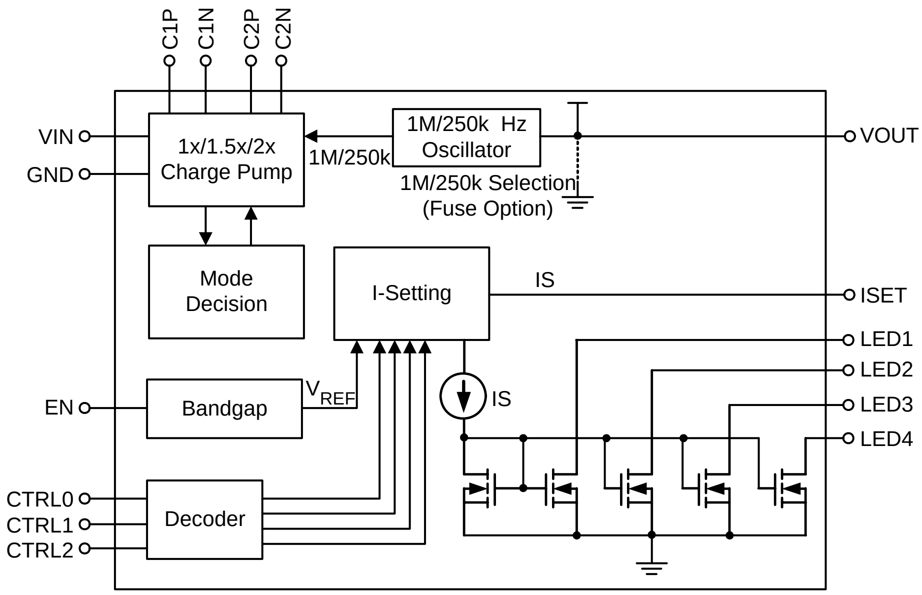


Table 1

Control Inputs			Output Status			
CTRL 2	**CTRL 1**	**CTRL 0**	**LED 4**	**LED 3**	**LED 2**	**LED 1**
0	0	0	OFF	OFF	OFF	ON
0	0	1	OFF	OFF	ON	OFF
0	1	0	OFF	ON	OFF	OFF
0	1	1	ON	OFF	OFF	OFF
1	0	0	OFF	OFF	ON	ON
1	0	1	OFF	ON	ON	ON
1	1	0	ON	ON	ON	ON
1	1	1	OFF	OFF	OFF	OFF

Operation

The RT9360 is a high efficiency charge pump white LED driver. It provides 4 channels low drop-out voltage current source to regulated 4 white LEDs current. For high efficiency, the RT9360 implements x1/x1.5/x2 mode charge pump. An external R_{SET} is used to set the current of white LED. RT9360 has a input current regulation to reduce the input ripple.

Soft Start

The RT9360 includes a soft start circuit to limit the inrush current at power on and mode switching. Soft start circuit holds the input current level long enough for output capacitor C_{OUT} reaching a desired voltage level. When the soft start off, the RT9360 won' t sink spike current from V_{IN}.

Mode Decision

The RT9360 uses a smart mode decision method to select the working mode for maximum efficiency. Mode decision circuit senses the output and LED voltage for up/down selection.

Dimming Control

CTRL0, CTRL1 and CTRL2 are used to control the on-off of White LED. When a external PWM signal is connected to the control pin, brightness of white LED is adjusted by the duty cycle.

LED Current Setting

The current of white LED connected to RT9360 can be set by R_{SET}. Every current flows through the white LED is 440 times greater than the current of R_{SET}. The white LED can be estimated by following equation:

$$I_{LED} = 440 \times \left(\frac{V_{ISET}}{R_{SET}}\right)$$

where V_{ISET} = 1.1V, and R_{SET} is the resistance connected from ISET to GND.

Thermal Shutdown

The RT9360 provides a high current capability to drive 4 white LEDs. A thermal shutdown circuit is needed to protect the chip from thermal damage. When the chip reaches the shutdown temperature 150°C, the thermal shutdown circuit turns off the chip to prevent the thermal accumulation in the chip.

Overvoltage Protection

The RT9360 regulates the output voltage by controlling the input current. When the output voltage reaches the designated level, the RT9360 reduces the input current. And then, the output voltage regulation also serves an overvoltage protection.

Short Circuit Protection

A current limiting circuit is also included in the RT9360 for short circuit protection. Whenever output source a dangerously high current, the current limiting circuit takes over the output regulation circuit and reduces the output current at an acceptable level.

Absolute Maximum Ratings (Note 1)

- Input Voltage ---------- –0.3 to 6V
- Output Voltage ---------- –0.3 to 6V
- Power Dissipation, P_D @ T_A = 25°C
  VQFN–16L 4X4 ---------- 2.5W
- Package Thermal Resistance (Note 4)
  VQFN–16L 4x4, θ_{JA} ---------- 40°C/W
- Junction Temperature ---------- 150°C
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Junction Temperature Range ---------- –40°C to 125°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 2)
  HBM (Human Body Mode) ---------- 2kV
  MM (Machine Mode) ---------- 200V

Recommended Operating Conditions (Note 3)

- Ambient Temperature Range ---------- –40°C to 85°C

Electrical Characteristics

(V_{IN} = 2.85V to 5.5V, C1 = C2 = 1.0μF (ESR = 0.03Ω, T_A = 25°C, unless otherwise specified)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Units
Input Supply Voltage		V_{IN}		2.5		5.5	V
Undervoltage Lockout Threshold			V_{IN} rising	1.8	2.2	2.4	V
Undervoltage Lockout Hysteresis				--	50	--	mV
Current into LEDs 1, 2, 3 and 4		I_{LED}	R_{SET} = 24kΩ	18.5	20	21.5	mA
			R_{SET} = 91kΩ	4.5	5	5.5	mA
			2.7V < V_{IN} < 5.5V	2	--	20	mA
			3.1V < V_{IN} < 5.5V	2	--	30	mA
Quiescent Current	RT9360A	I_Q	F_{OSC}=250KHz, EN = High, No Load	--	1.5	2.0	mA
	RT9360B		F_{OSC}=1MHz, EN = High, No Load	--	3	4	mA
	RT9360A/B		V_{IN} = 4.2V, EN = Low	--	1	10	uA
I_{LED} Accuracy (Note 5)		$I_{LED-ERR}$	2mA < I_{LED} < 30mA	--	2	7.5	%
Current Matching (Note 6)		$I_{LED-LED-ERR}$	2mA < I_{LED} < 30mA	--	1	5	%
1x mode to 1.5x mode Transition Voltage (V_{IN} falling)		$V_{TRANS1X}$	V_{LED}= 3.5V, I_{OUT}= 80mA I_{LED1} = I_{LED2} = I_{LED3} = I_{LED4} = 20mA	--	3.75	3.85	V
1.5x mode to 2x mode Transition Voltage (V_{IN} falling)		$V_{TRANS1.5X}$	V_{LED}= 3.5V, I_{OUT}= 80mA I_{LED1} = I_{LED2} = I_{LED3} = I_{LED4} = 20mA	--	2.85	2.95	V
Oscillator Frequency		F_{OSC}	RT9360A	200	250	300	kHz
			RT9360B	0.8	1.0	1.2	MHz
Input Current Limit		I_{LIMIT}	Short Circuit applied from V_{OUT} to GND	250	400	650	mA
Output Over Voltage Protection		V_{OVP}	Open circuit at any LED that is programmed to be in the on state	--	5.5	6	V

To be continued

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Input High Threshold	V_{IH}	Input high logic threshold (EN, CTRL0, CTRL1, CTRL2)	1.5	--	--	V
Input Low Threshold	V_{IL}	Input low logic threshold (EN, CTRL0, CTRL1, CTRL2)	--	--	0.4	V
Input High Current	I_{IH}	$V_{IH} = V_{IN}$	--	--	1	uA
Input Low Current	I_{IL}	V_{IL} = GND	--	--	1	uA
Thermal Shutdown Threshold			140	150	180	°C
Thermal Shutdown Hysteresis			--	10	--	°C

Note 1. Stresses listed as the above "Absolute Maximum Ratings" may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.

Note 2. Devices are ESD sensitive. Handling precaution recommended.

Note 3. The device is not guaranteed to function outside its operating conditions.

Note 4. θ_{JA} is measured in the natural convection at T_A = 25°C on a low effective thermal conductivity test board of JEDEC 51-3 thermal measurement standard.

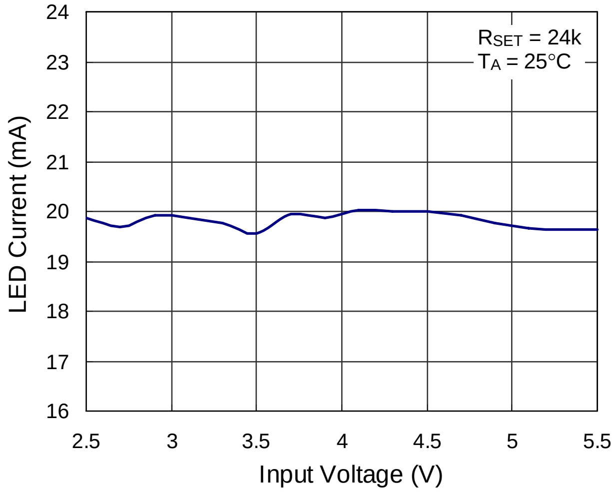
Note 5. $I_{LED(ERR)} = \left|\frac{I_{LED(MEA)} - I_{LED(SET)}}{I_{LED(SET)}}\right| \times 100\%$

Note 6. Current Matching refers to the difference in current from on LED to the next.

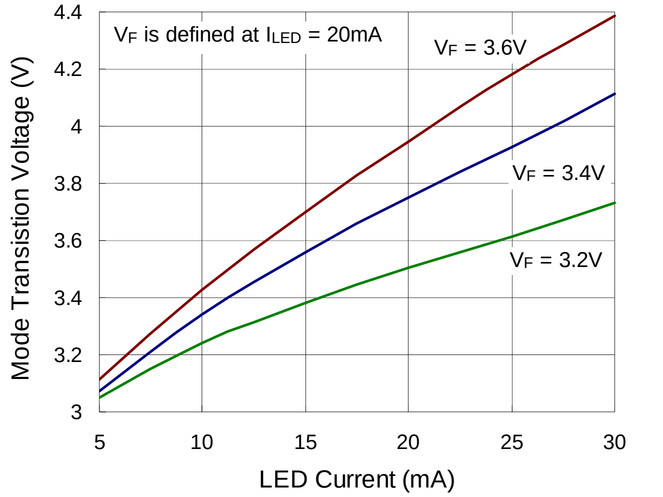
$$I_{LED}\text{ Current Matching} = \left|\frac{I_{LED(MAX)} - I_{LED(MIN)}}{I_{LED(MAX)} + I_{LED(MIN)}}\right| \times 100\%$$

Typical Operating Characteristics

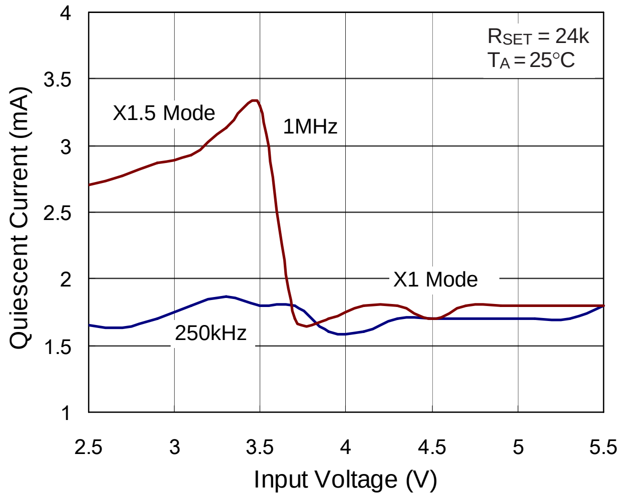
LED Current vs. Input Voltage



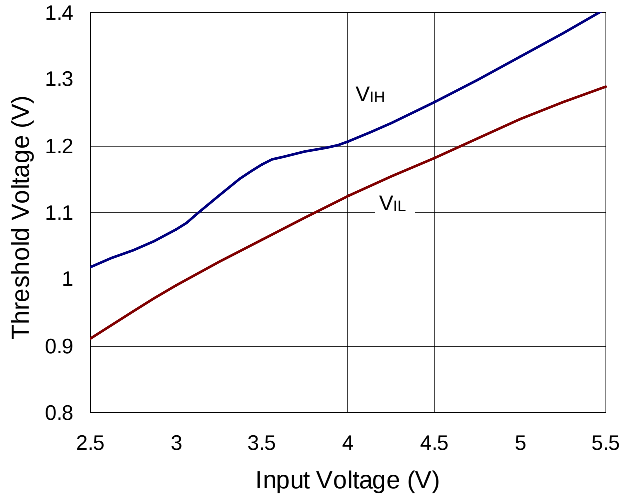
X1 to X1.5 Mode Transition Voltage vs. LED Current



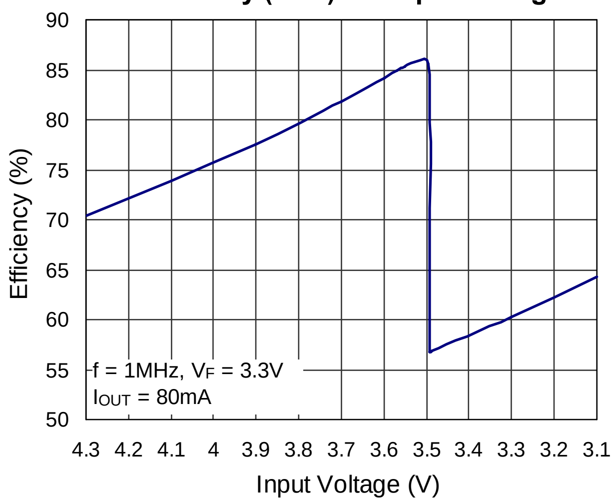
Input Voltage vs. Quiescent Current



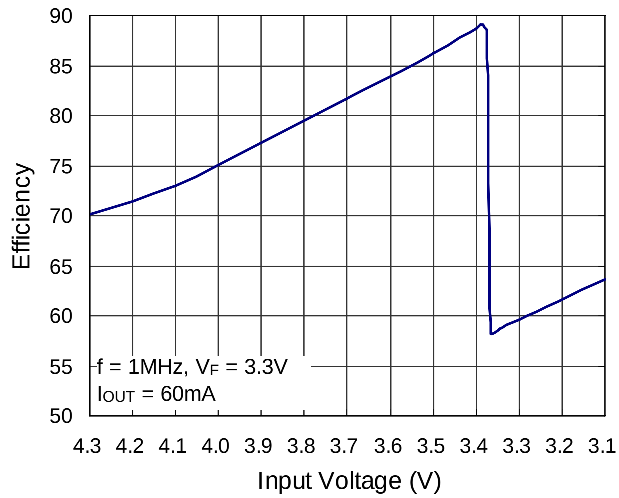
Logic Threshold Voltage vs. Input Voltage



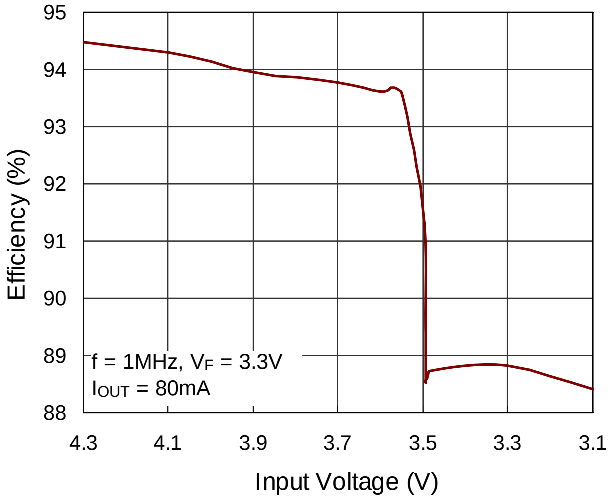
Efficiency (LED) vs. Input Voltage



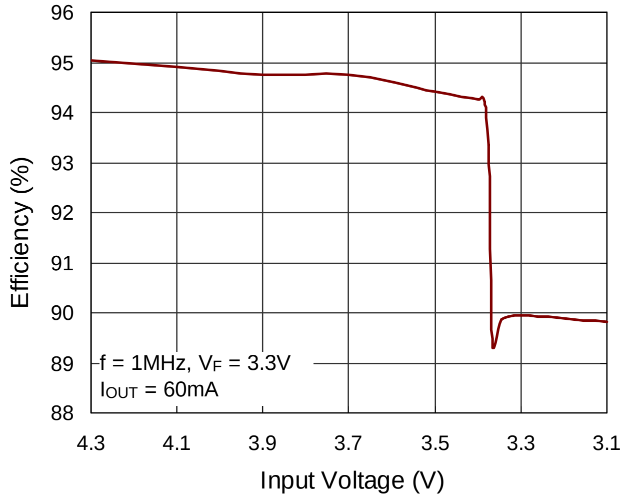
Efficiency (LED) vs. Input Voltage



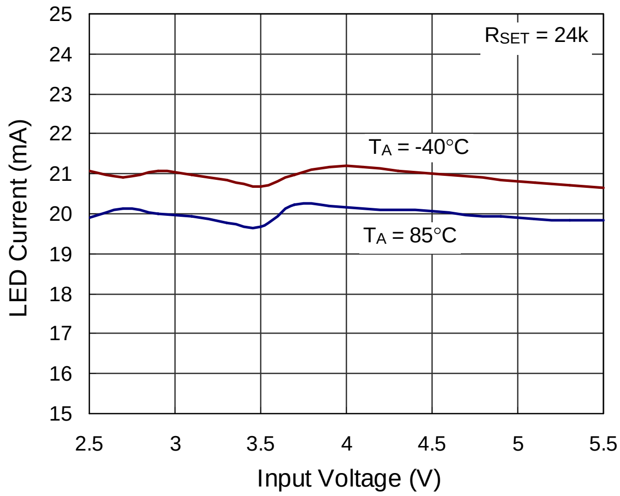
Efficiency (Converter) vs. Input Voltage



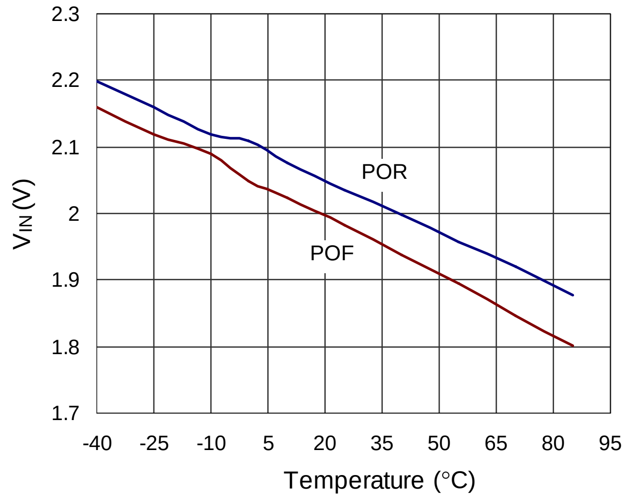
Efficiency (Converter) vs. Input Voltage



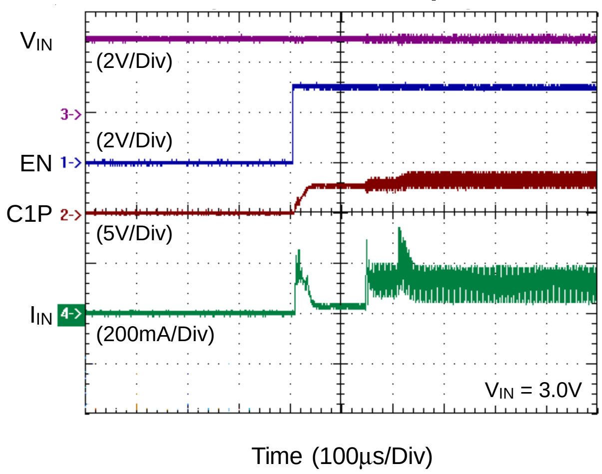
LED Current vs. Input Voltage



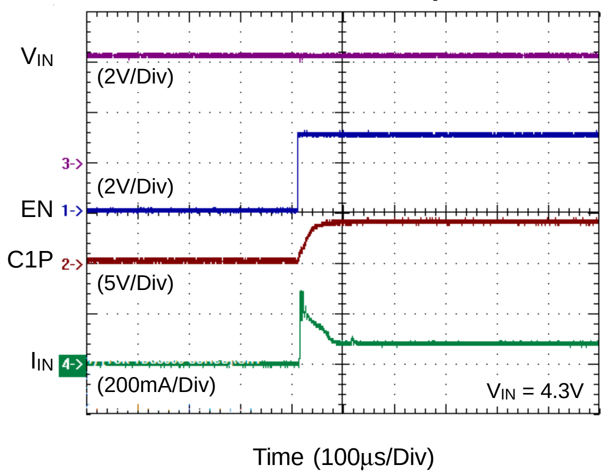
UVLO Voltage vs. Temperature



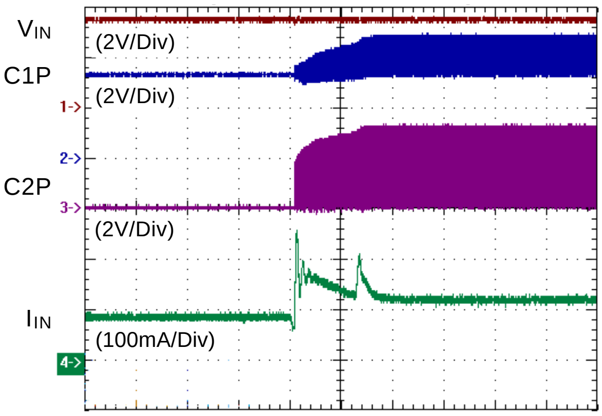
Inrush Current Response



Inrush Current Response

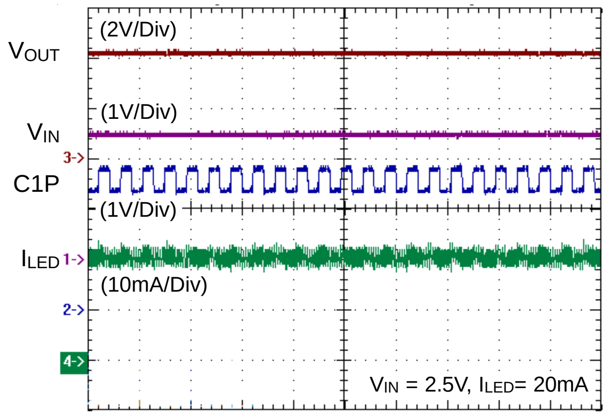


Mode Change Inrush Current (X1 to X1.5)



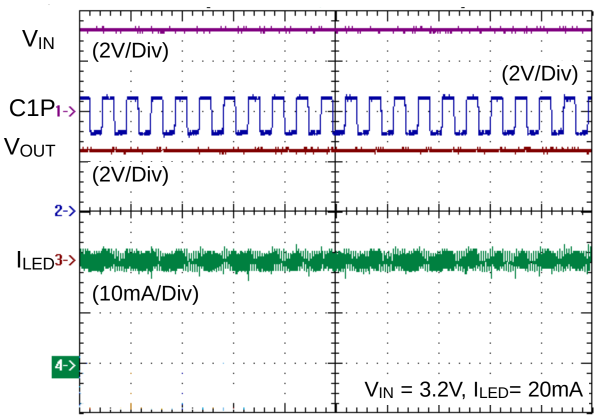
Time (40μs/Div)

Normal Operation



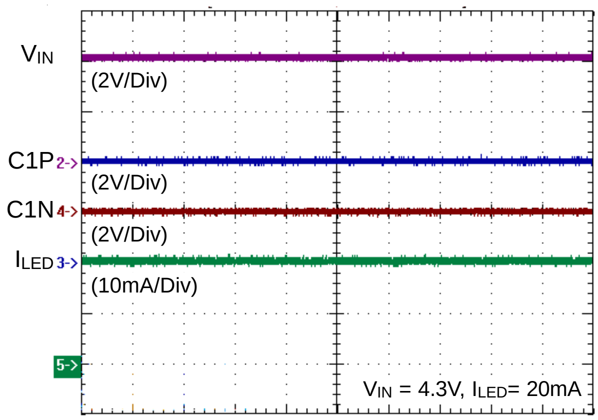
Time (2μs/Div)

Normal Operation



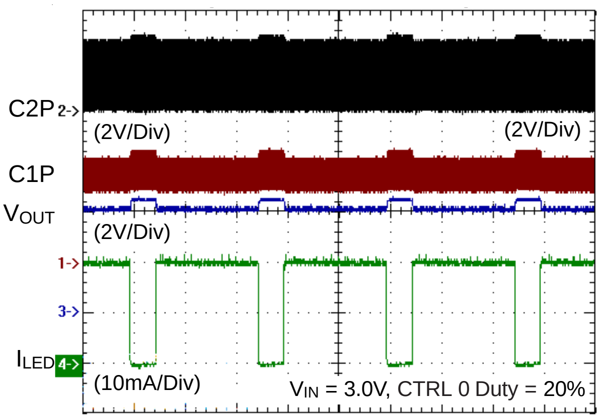
Time (2μs/Div)

Normal Operation



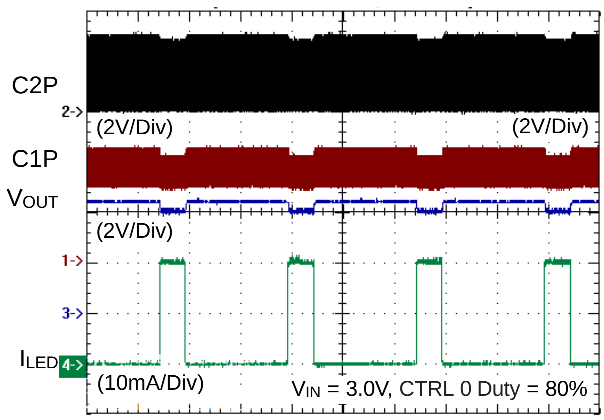
Time (2μs/Div)

Dimming Operation



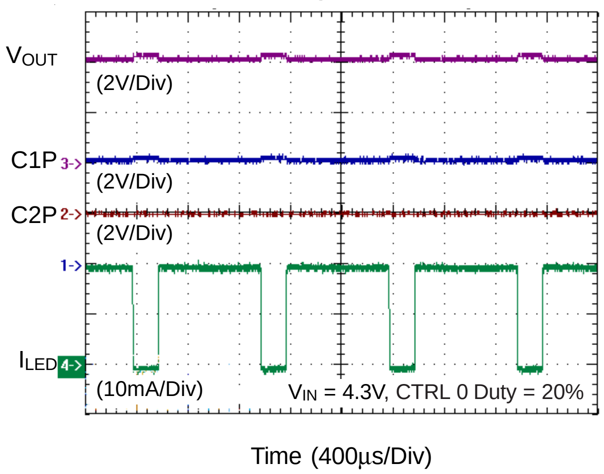
Time (400μs/Div)

Dimming Operation

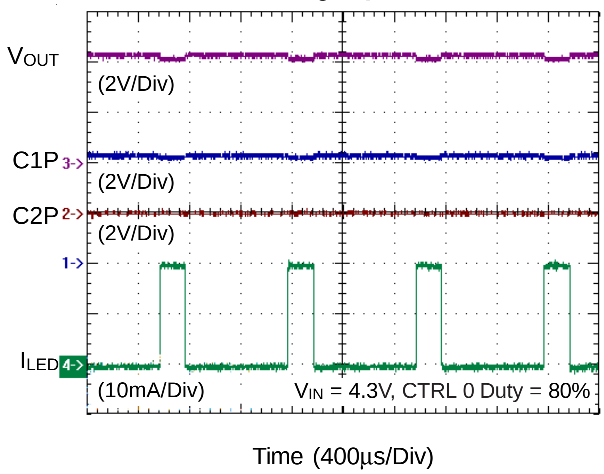


Time (400μs/Div)

Dimming Operation



Dimming Operation



Applications Information

Selecting Capacitors

To get the better performance of RT9360, the selecting of peripherally appropriate capacitor and value is very important. These capacitors determine some parameters such as input and output ripple, power efficiency, maximum supply current by charge pump, and start-up time. To reduce the input and output ripple effectively, the low ESR ceramic capacitors are recommended.

Generally, to reduce the output ripple, increasing the output capacitance C_{OUT} is necessary. However, this will increase the start-up time of output voltage.

For LED driver applications, the input voltage ripple is more important than output ripple. Input ripple is controlled by input capacitor C_{IN}, increasing the value of input capacitance can further reduce the ripple. Practically, the input voltage ripple depends on the power supply's impedance. If a single input capacitor C_{IN} cannot satisfy the requirement of application, it is necessary to add a low-pass filter. Figure 1 shows a C-R-C filter used on RT9360A. The input ripple can be reduced less than 30mVp-p when driving 80mA output current.

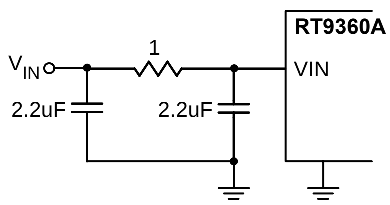


Figure 1. C-R-C filter used to reduce input ripple

The flying capacitor C_1 and C_2 determine the supply current capability of the charge pump and to influence the overall efficiency of system. The lower value will improve efficiency, but it will limit the LED's current at low input voltage. For 4 X 20mA load over the entire input range of 2.7 to 5.5V, a capacitor of 1μF is optimal.

Setting the LED Current

The RT9360 can be set a fixed LEDs current by a resister R_{SET} connected from I_{SET} to GND. R_{SET} establishes the reference current and mirrors the current into LED1, LED2, LED3, and LED4. The current into LED is about 440 times of the current flows through the R_{SET}, the approximate setting formula is given as follows:

$$I_{LED} = \frac{484(V)}{R_{SET}(\Omega)} \quad (1)$$

Figure 2 shows the typical value of R_{SET} versus average LED current and Table 1 shows the values of R_{SET} for a fixed LED current.

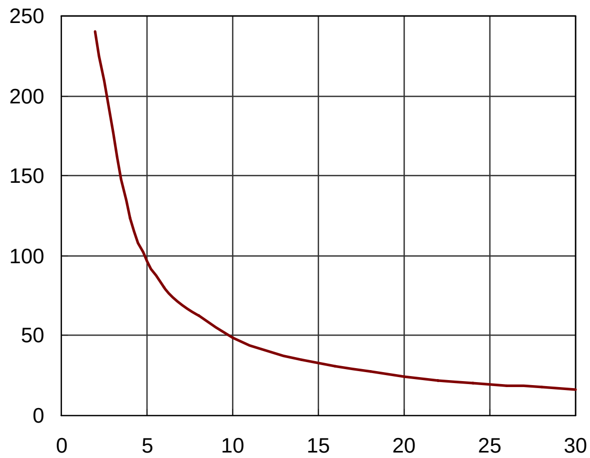


Figure 2. The typical curve of R_{SET} vs. LED's average current.

Table 1. R_{SET} Value Selection

I_{LED} (mA)	R_{SET} (kΩ)	Nearest Standard Values for R_{SET} (kΩ)
5	91.0	91.0
10	47.9	47.5
15	32.7	32.4
20	24.0	24.0
25	19.6	19.6
30	16.4	16.5

If maximum accuracy is required, a precision resister is needed. Equation (2) shows how to calculate the error $I_{LED(ERR)}$.

$$I_{LED(ERR)} = \left| \frac{I_{LED(MEA)} - I_{LED(SET)}}{I_{LED(SET)}} \right| \times 100\% \quad (2)$$

Where $I_{LED(MEA)}$ is practical LED current

$I_{LED(SET)}$ is LED current which is determined by the R_{SET}.

- **LED current setting with NMOS**

LED current setting control can also be achieved by used the external NMOS to change equivalent resister of ISET pin. Figure 3 shows this application circuit of method. For this example, a 3 bit signals can set 8 kinds of different equivalent resister of ISET pin, i.e. produce 8 kinds of LED current level. Table 2 shows the relation between equivalent resister of ISET pin and control signal.

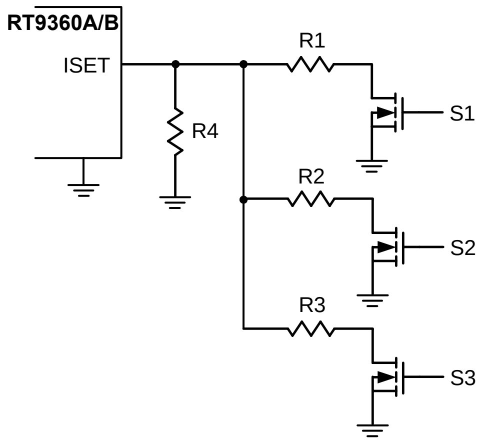


Figure 3. The application circuit of setting LED current which using a NMOS to set R_{SET}.

Table 2. The relation between control signal and equivalent resister of ISET pin

S1	S2	S3	Equivalent Resister of I_{SET} pin (R_{SET})
0	0	0	$R_{SET} = R_4$
0	0	1	$R_{SET} = R_3//R_4$
0	1	0	$R_{SET} = R_2//R_4$
0	1	1	$R_{SET} = R_2//R_3//R_4$
1	0	0	$R_{SET} = R_1//R_4$
1	0	1	$R_{SET} = R_1//R_3//R_4$
1	1	0	$R_{SET} = R_1//R_2//R_4$
1	1	1	$R_{SET} = R_1//R_2//R_3//R_4$

LED Dimming Control Methods

The RT9360 can use two methods to achieve the LED dimming control. These methods are detailed described as following:

(1). Dimming using PWM signal into CTRL0, CTRL1, and CTRL2

LED current can be controlled by applying a PWM signal to CTRL0, CTRL1, or CTRL2. Table3 shows the relation between CTRLx and 4 LED's current states. For an example, as the CTRL1 and CTRL2 are pulled logical high and CTRL0 receives a PWM signal, then, four LEDs will be dimmed synchronously. Here, the PWM signal setting the LED's current ON/OFF can achieve the average LED's current which in design. The application circuit is shown in Figure 4. Figure 5, and Figure 6 show 3WEDs and 2WLEDs PWM dimming application circuit, respectively. During the time of PWM signal logical low, the current is a fixed value and setting by R_{SET} resistor. So the average LEDs current can be approximated as Equation (3).

$$I_{LED(AVG)} = \frac{T_{OFF} \times I_{LED(ON)}}{T_{PWM}} \quad (3)$$

Where:

T_{PWM} is the period of PWM dimming signal

T_{OFF} is the time of PWM signal at low.

$I_{LED(ON)}$ is LED on state current.

Table 3. The relation between CTRLx and 4 LED's's current states

Control Inputs			Output Status			
CTRL0	CTRL1	CTRL2	LED1	LED2	LED3	LED4
0	0	0	ON	OFF	OFF	OFF
1	0	0	OFF	ON	OFF	OFF
0	1	0	OFF	OFF	ON	OFF
1	1	0	OFF	OFF	OFF	ON
0	0	1	ON	ON	OFF	OFF
1	0	1	ON	ON	ON	OFF
0	1	1	ON	ON	ON	ON
1	1	1	OFF	OFF	OFF	OFF

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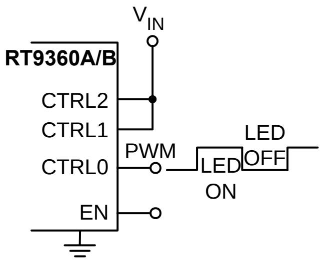


Figure 4. The PWM dimming application circuit for 4WLEDs

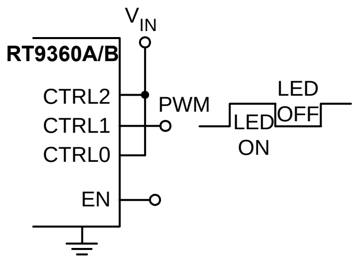


Figure 5. The PWM dimming application circuit for 3WLEDs

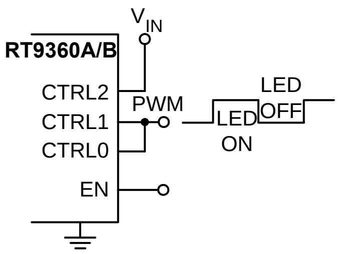


Figure 6. The PWM dimming application circuit for 2WLEDs

Besides, RT9360 has 100us delay time between mode transfer. This delay time makes different dimming frequency corresponds to different maximum duty of CTRLX pin. When the duty cycle of dimming frequency excess maximum duty, the RT9360s can' t transfer the mode normally. Equation (4) shows the relation between maximum duty of CTRLX pin and PWM dimming frequency. Table 4 is shown the common dimming frequency and its corresponding maximum duty. For better performance consideration, the maximum PWM dimming frequency is recommended below 1kHz.

$$D_{MAX} = (1 - 100 \times 10^{-6} \times F_D) \quad (4)$$

Where : D_{MAX} is Maximum Duty of CTRLX

F_D is PWM Dimming Frequency

Table 4. The common dimming frequency and its corresponding maximum duty.

Dimming Frequency (Hz)	CTRLX Maximum Duty	ILED Minimum Duty
1K	0.90	0.10
900	0.91	0.09
800	0.92	0.08
700	0.93	0.07
600	0.94	0.06
500	0.95	0.05
400	0.96	0.04
300	0.97	0.03
200	0.98	0.02

(2). The PWM dimming by GPIO

The PWM dimming by GPIO is shown as Figure 7. DZ shall be a Schottky diode with forward voltage less than 0.3V at I_F = 1mA. C3 is a capacitor to keep the enable pin voltage is higher than the threshold voltage. R1 is discharge resister and it should be not too high to prevent the off time too long while turned-off. The recommended conditions are shown as following.

1. The recommended value for R1 and C3 are 200kΩ (±5%) and 0.22uF (X7R, ±10%).
2. The forward voltage of the Schottky diode shall be less than 0.3V at 1mA.
3. The output voltage of GPIO should be greater than 2.8V and keep the voltage on EN pin is higher than 1.5V.
4. The PWM frequency should be in the range of 500Hz~1.5kHz or 20kHz~30kHz for audio noise consideration.
5. The PWM duty cycle shall be in the range of 30% to 95%.
6. The driving capability of the GPIO should be greater than 2mA @ 2.8V.
7. The LED current can be obtained by the equation,

$$I_{LED} = 440 \times \frac{V_{ISET}}{R_{SET}} \times (1 - D_{PWM})$$

(The typical value of V_{ISET} is 1.1V)

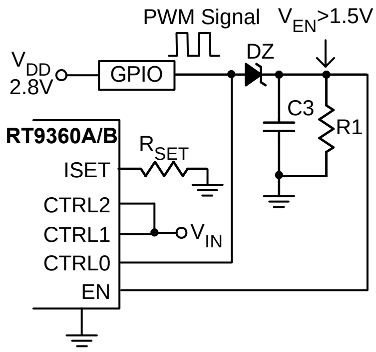


Figure 7. The GPIO PWM dimming application circuit

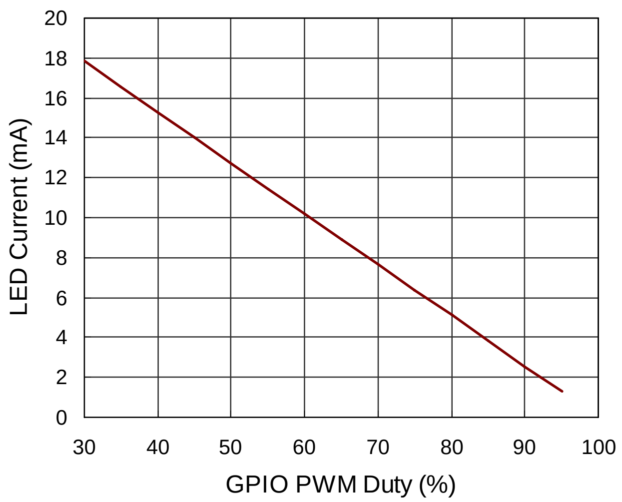
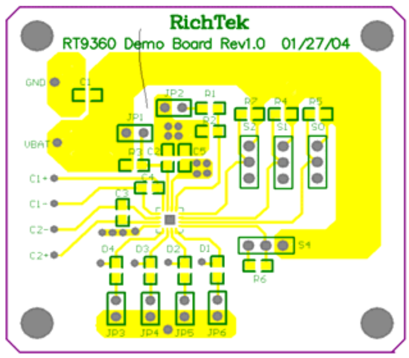


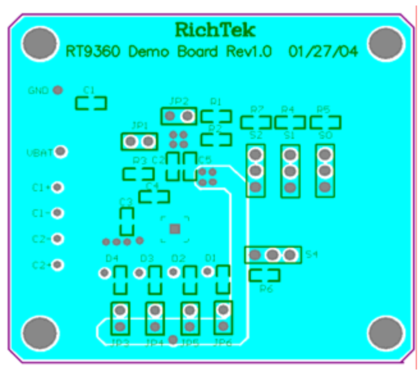
Figure 8. GPIO PWM dimming duty v.s. I_{LED} current (R_{SET} = 19kΩ)

PCB Board Layout

The RT9360 is a high-frequency switched-capacitor converter. For best performance, place all of the components as close to IC as possible. Besides a solid ground plane is recommended on the bottom layer of the PCB. The ground should be connected C_{IN} and C_{OUT} together and as close to the IC as possible. Figure 9 shows the typical layout of RT9360' s EVB board.



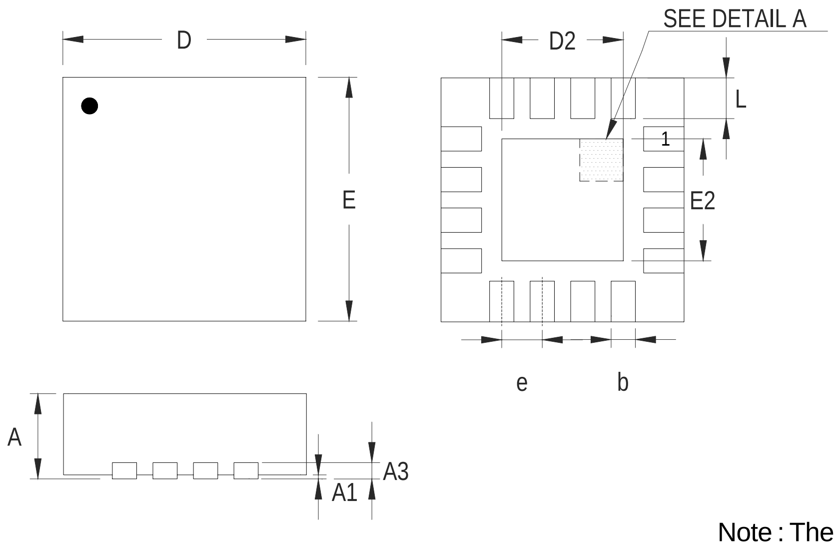
Top Layer

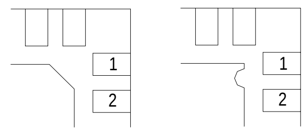


Bottom Layer

Figure 9. The typical layout of RT9360' s EVB board

Outline Dimension





DETAIL A

Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.800	1.000	0.031	0.039
A1	0.000	0.050	0.000	0.002
A3	0.175	0.250	0.007	0.010
b	0.250	0.380	0.010	0.015
D	3.950	4.050	0.156	0.159
D2	2.000	2.450	0.079	0.096
E	3.950	4.050	0.156	0.159
E2	2.000	2.450	0.079	0.096
e	0.650		0.026	
L	0.500	0.600	0.020	0.024

V-Type 16L QFN 4x4 Package

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