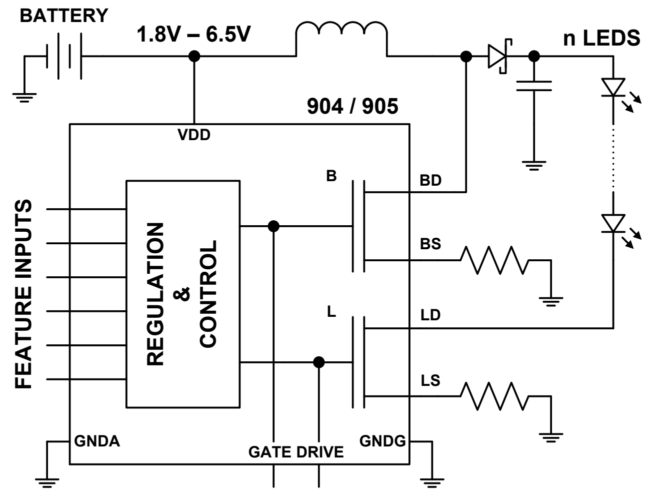
LED DRIVER AND POWER MANAGER

- Portable lighting applications
- 1.8 to 6.5 volts input
- 128 to 1 brightness control, 15 settings
- Instant full-brightness control
- Constant current output up to 40 volts
- Low battery warning (adjustable)
  - Discharged battery shut-off
- Auto shut-off (enabled by user)
- < 10μA off current
- Internal power FETs, 2A / 1A
- Gate drive for external devices
- Special modes: Flashing and SOS



QFN 24 Ld 4x4mm

#	PIN	DESCRIPTION
1	BS1	Source B FET
2	BS2	Source B FET
3	LS	Source L FET
4	FB	Full Brightness
5	SW0	Switch to GNDA
6	LBD	Low Battery Detector
7	OVP	Over Voltage Detector
8	VDD	Supply
9	nc9	No Connect
10	D	Decrease Brightness
11	nc11	No Connect
12	GNDA	Supply Return
13	U	Increase Brightness
14	MO	Toggle ON / OFF
15	EN	Enable ON
16	LD	Drain L FET
17	BD2	Drain B FET
18	BD1	Drain B FET
19	nc19	No Connect
20	VCC	Gate Drive Supply
21	LG	L Gate Ext Drive
22	GNDG	Gate Drive Return
23	BG	B Gate Ext Drive
24	EGE	Enable Ext Gate Drive
-	DAP	Gate Drive Return

The 904 / 905 parts provide portable lighting products the ability to control brightness over a 128 to 1 range, monitor battery status, and operate as a signaling device. This allows the user to fine tune the light output for the application and maximize battery run-time. The low off-current permits continuous connection to the battery for years of standby operation.

These products combine the features found in systems using discrete parts, a LED driver and micro controller into one 4x4 mm QFN package.

The 904 / 905 have been optimized for battery voltages between 1.8 and 6.5 volts. The internal power devices of the 904 have lower on resistance and lower breakdown voltage than the 905. Both can drive 1 A.

The 904 can drive up to 5 white LED's, whereas the 905 can drive up to 10 white LED's in series. Both devices can drive external power FETs through the BG and LG pins if greater power handling is required. BG and LG are enabled by connecting EGE to GNDG.

904 / 905 Electrical Characteristics

Tj=25C, VCC=VDD = 3 V, unless otherwise stated

Parameter	Test Condition	Symbol	Min	Typ	Max	Units
Operating						
Device Supply		VDD	1.8	3.0	6.5	V
Gate Supply		VCC	1.6	3.0	6.5	V
Off current into VDD, VCC, BD, LD	VDD = 3.0V, digital inputs = VDD	IOFF3	--	4	10	µA
	VDD = 6.5V, digital inputs = VDD	IOFF6	--	13	20	µA
On Current into VDD and VCC	1.8 $\le$ VDD $\le$ 6.5, VCC = VDD, EGE = VCC	IDD	0.5	1.5	2.5	mA
Auto Shut-off warning	Enabled with UP/ DN	taw	13	15.5	19	minutes
Auto Shut-off		tauto	--	taw+2	--	minutes
Beacon flashing rate	Enabled with UP/ DN	Fbcn	55	65	75	fpm
Thermal Resistance	Junction to exposed pad	θ_{JC}	--	6	--	C/W
Junction Temperature	Operating	Tc	-20		125	C

Boost Converter

Parameter	Test Condition	Symbol	Min	Typ	Max	Units
Break down voltage	BVs = 0, IBD = 1 mA	BVbd				V
904			24	--	--	
905			42	--	--	
On Resistance	VCC = 3.5, IBD = 100 mA, pins 1-2 to 17-18	BRdson				ohms
904				0.23		
905				0.31		
Start-up On Resistance	VCC = 1.6, IBD = 100 mA	BRstart				ohms
904				0.5		
905				1.0		
Max BD current	Average on-time current < 75% of peak current. BD1 and BD2 shorted. BS1 and BS1 shorted. Switch operation.	IBDmax	--	--	2.67	A
PWM Frequency		fp	570	667	770	KHz
PWM Period	VDD=3.0	tp	1.3	1.5	1.75	µsec
	VDD=1.8		--	1.6	--	
	VDD=6.5		--	1.4	--	
PFM Period		tt	tp	--	7.67tp	µsec
Leading Edge Blanking		tb	55	68	80	nsec
Fault time		tf	220	250	290	nsec
On Time (nominal)		tc	0.167tp	--	7.333tp	µsec
Off Time		td	0.33tp	0.5	0.833tp	µsec
Sense threshold	VCC = 3.0	VBs		0.2		V
Sense Offset Resistance	Pins 1 and 2 shorted	RBs		0.033		ohms

904 / 905 Electrical Characteristics

Tj=25C, VCC=VDD = 3 V, unless otherwise stated

Parameter	Test Condition	Symbol	Min	Typ	Max	Units

LED Modulator

Parameter	Test Condition	Symbol	Min	Typ	Max	Units
Break down voltage						V
904	BVs = 0, ILD = 1 mA	LVbd	24	--	--	
905	ILD = 1 mA		42	--	--	
On Resistance						ohms
904	VCC = 3.5	LRdson		0.46		
905	IBD = 100 mA			0.62		
Max LD current	Switch operation	ILDmax	--	--	1	A
PWM Frequency	tp = 1.5 µsec	Lfp	--	244	--	Hz
PWM Period	tp = 1.5 µsec	Ltp	--	4.1	--	msec
Leading Edge Blanking		tbl	110	136	160	nsec
Sense threshold		VLs	--	0.2	--	V
Fault Sense threshold		LVsf	--	0.4	--	V
Sense Offset Resistance		RLs		0.066		ohms

External Gate Drive

Parameter	Test Condition	Symbol	Min	Typ	Max	Units
On Resistance BG, LG	VOL, VCC = 3.5, IG = 100 mA	GNdson		5	10	ohms
	VOH, VCC = 3.5, IG = -100 mA	GPdson		6	12	ohms

Analog

Parameter	Test Condition	Symbol	Min	Typ	Max	Units
SW0 on resistance	VDD = 1.8, Isw0 = 5 mA	Rsw0	--	4	20	ohms
LBD warning threshold		VLBW	--	0.5	--	V
LBD warning debounce		tlbw	--	163	--	msec
LBD shut-off threshold	VDD = 1.8	VLBX	--	0.465	--	V
	VDD = 3.0	VLBX	0.455	0.467	0.479	V
	VDD = 6.5	VLBX	--	0.475	--	V
LBD shut-off debounce	First Occurrence	tlbxw		20		sec
OVP threshold		VOVP		0.5		V

Digital

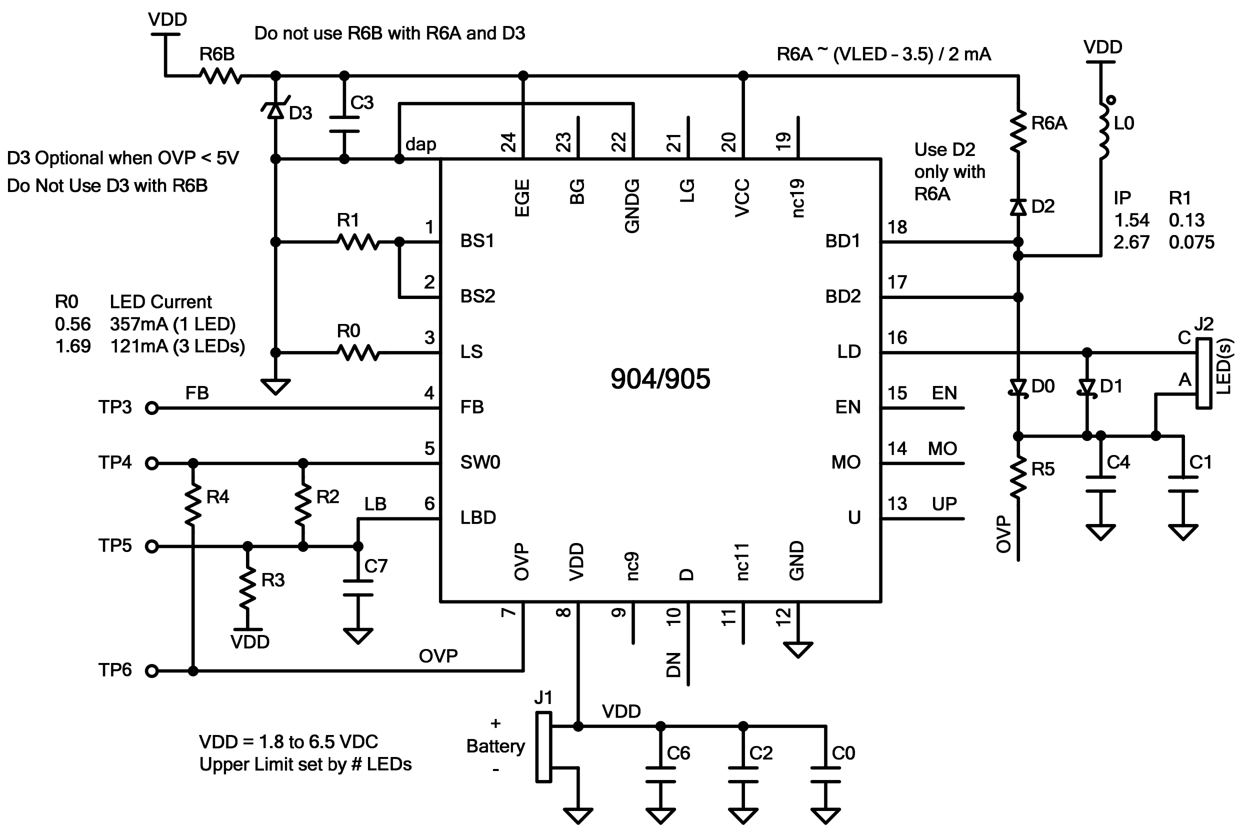
Parameter	Test Condition	Symbol	Min	Typ	Max	Units
EN (enable) Thresholds						
Low Threshold	VDD = 1.8	VL_EN	--	0.85	--	V
	VDD = 3.0	VL_EN	0.60	0.90	1.30	V
	VDD = 6.5	VL_EN	--	0.95	--	V
High Threshold	VDD = 1.8	VH_EN	--	0.95	--	V
	VDD = 3.0	VH_EN	0.70	1.00	1.40	V
	VDD = 6.5	VH_EN	--	1.05	--	V
Hysteresis	VDD = 1.8	Hys_EN	--	100.00	--	mV
	VDD = 3.0	Hys_EN	60.00	110.00	250.00	mV
	VDD = 6.5	Hys_EN	--	120.00	--	mV

904 / 905 Electrical Characteristics

Tj=25C, VCC=VDD = 3 V, unless otherwise stated

Parameter	Test Condition	Symbol	Min	Typ	Max	Units
Digital (cont'd)						
EN Pull-up Current		IL_EN	0.5	1.0	2.5	uA
EN Debounce		tdb_EN		40		msec
EGE Threshold Low		VL_EGE			0.3VCC	V
EGE Threshold High		VH_EGE	0.7VCC			V
EGE Input Current		I_EGE	-2	0	2	µA
MO, UP, DN, FB threshold		VL		0.9		V
		VH		1.0		V
MO Pull-up Current		IL_MO		8.0		µA
UP, DN, FB pull-up current	part disabled	ILOFF		1.0		µA
	part enabled	ILON		8.0		µA
MO Debounce		tdb_MO		40		msec
UP, DN Debounce		tdb_UP, tdb_DN		106		msec

BOOST APPLICATION SCHEMATIC



These products combine a boost regulator to accommodate varying battery voltages with a PWM brightness circuit to manage the brightness and signaling functions of the LED. This combination assures constant light output over the battery operating range and allows the user to make the trade-off between light output and battery life.

The control loop for the boost regulator is digital. Only two external current sense resistors are required: one for the boost at the BS pins and the other for the LED at the LS pin. Internal comparators use a 200 mV reference to monitor the currents through these pins.

This minimizes component count and simplifies the design process for stable operation to selecting values for two resistors, one inductor, and the output capacitor.

Current flowing in the LED regulates the operation of the regulator, which can also be used as a SEPIC regulator. When the LED is operating below its target current, the boost regulator supplies additional energy to the output until the LED target current is reached.

To protect the device from an open-circuit LED, an over-voltage-protection (OVP) pin is used to sense the LED voltage. When the LED voltage is too high, the boost regulator is disabled. An external resistor divider network selects the proper protection voltage.

The LED PWM circuit also protects the LED from over-current. When the LED current is twice its target current, the LED PWM circuit enters a fault mode to limit the on-time to less than 1 microsecond and the duty to less than 1 percent until the fault is cleared. This protects series LEDs from shorts or excess battery voltage.

The battery voltage can be monitored through the LBD pin. When the battery voltage is near its minimum operating voltage, the LED output is modulated to indicate a low battery condition; this warns the user of the low battery condition before reaching the shut-off point. Because the LED current is held constant over varying battery conditions, this is the only indication of a low battery and avoids the typical collapse in light output without warning. It also provides the user the opportunity to change the battery before the product automatically shuts off.

Operating a battery below its cut-off voltage can result in damage to the battery (especially rechargeables) and the product from battery leakage. When the LBD pin drops below its lower limit (shut-off), the product is disabled after approximately 20 seconds. This provides ample warning without compromising battery integrity.

The "Off" current for the 904 / 905 products is less than 10 uA. The small off current allows the product to supply pull up current for ON / OFF controls with minimal effect on battery life. Continuous battery connection maintains brightness and mode settings. Conduction through the OVP and LBD pin resistor networks is eliminated by using the SW0 pin as their return. When the product is disabled SW0 is open circuit.

Operating Modes

There are two ways to enable the product: momentary contact closure (MO) and continuous contact closure (EN). Both MO and EN are active low with active pull-up currents and have contact debouncing circuitry. The debouncing time is approximately 40 milliseconds which prevents inadvertent enabling.

EN enables the product when it is low and disables when it is high. MO acts as an electronic toggle switch to enable on the first activation and disable on the second activation. However, MO cannot disable the product when EN is low. If the product was enabled through MO, the EN pin can be used to disable the product by taking EN low and then high.

An automatic shut-off feature can be enabled through the U input and disabled through the D input as discussed later. Cycling EN or MO will re-enable the part.

Signaling operation can be accomplished with momentary contact closure switches for both enable inputs (MO and EN): the EN for "signaling" and MO for continuous "ON/OFF" control.

Signaling can also be achieved by setting the product to minimum brightness and using the FB input as the signaling input, as discussed later.

LED brightness is controlled through one of three inputs: U, D, and FB. All are active low and have active pull-up currents. The U and D have debouncing:

U	Increases brightness
D	Decreases brightness
FB	Switch to full brightness

There are 15 brightness settings from full brightness (100% LED duty) to minimum brightness (0.78% LED duty). The LED modulation rate is approximately 244 Hz and brightness steps are near logarithmic. For every two steps the brightness either doubles or decreases by half. By default, the LED is set four steps below full brightness (25%).

Holding U or D active will cause auto stepping of the brightness; this is similar to the volume control of an audio product. The FB input is used to immediately switch to full brightness and can be used for signaling when the brightness is set below full brightness.

The U and D inputs also control other modes of the device (See the State and Mode patterns):

- Automatic Shut-Off
- Flashing / Beacon
- SOS

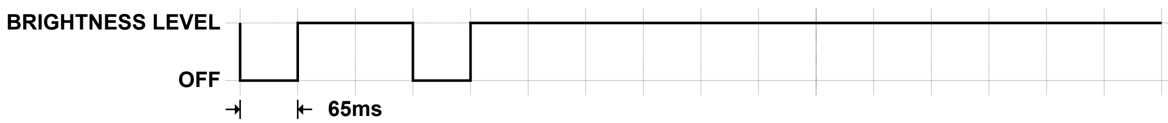
The automatic shut-off feature disables the product after 18 minutes. Prior to shut-off, the LED light will modulate for two minutes to warn the user of the automatic shut-off. During automatic shut-off warning, activating U or D will reset the timer for an additional 18 minutes without changing the brightness. By default the automatic shut-off feature is disabled. The automatic shut-off feature is always disabled in the Beacon / Flashing or SOS modes.

To enable automatic shut-off, the product is set to full brightness by the U input. The U input is then taken high for at least 1 second followed by low for at least 2 seconds. The LED will flash off periodically for a few seconds to indicate the automatic shut-off has been enabled.

To disable automatic shut-off, the product is set to minimum brightness by the D input. The D input is taken high for at least 1 second followed by low for at least 2 seconds. The LED will flash to full brightness periodically for a few seconds to indicate the automatic shut-off has been disabled.

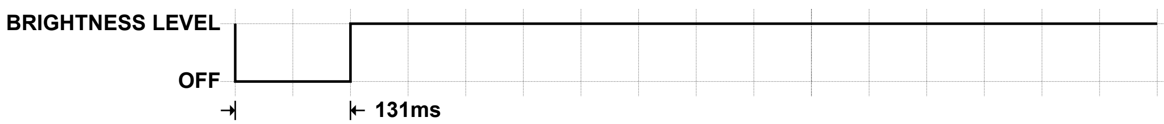
STATE & MODE PATTERNS

LOW BATTERY



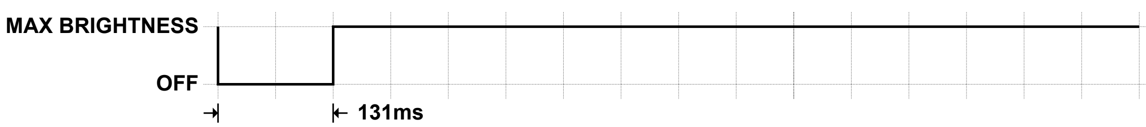
1 SECOND PATTERN
PATTERN REPEATED 4 TIMES UPON DETECTION OF LOW BATTERY, THEN SINGLE PATTERN EVERY 16 SECONDS AFTERWARDS

AUTO SHUT-OFF: WARNING



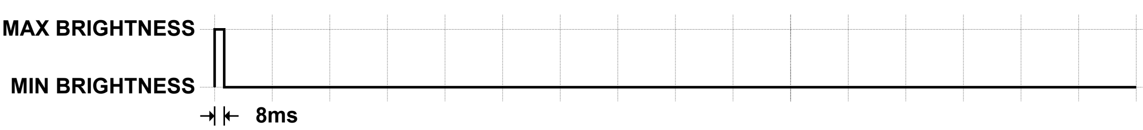
REPEATS PATTERN EVERY 4 SECONDS FOR 2 MINUTES UNTIL SHUT-OFF, OR BUTTON PRESS RESETS TIMER

AUTO SHUT-OFF: ENABLE



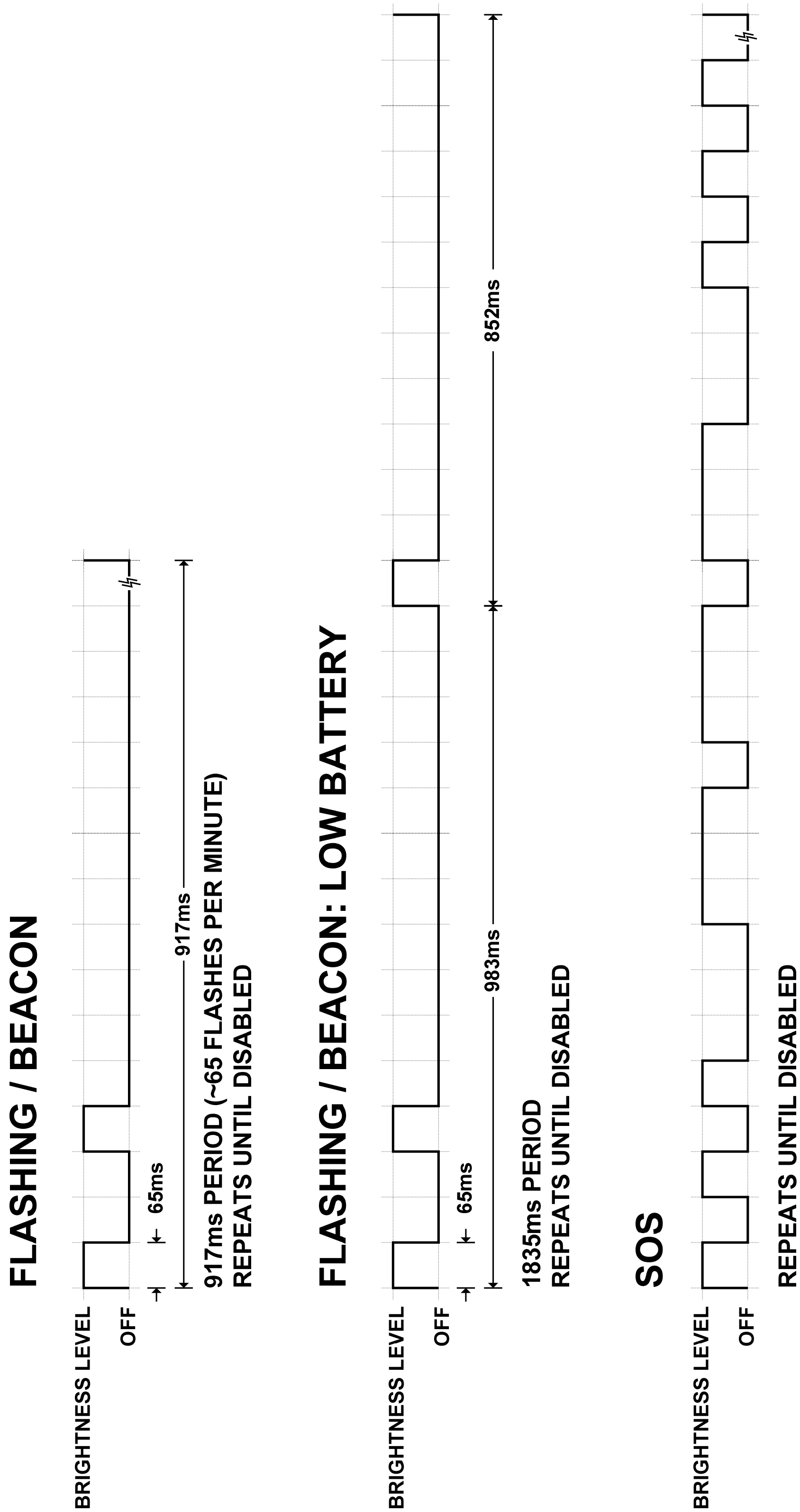
1 SECOND PATTERN
REPEATS 4 TIMES TO SIGNAL AUTO SHUT-OFF ENABLED

AUTO SHUT-OFF: DISABLE



1 SECOND PATTERN
REPEATS 4 TIMES TO SIGNAL AUTO SHUT-OFF DISABLED

STATE & MODE PATTERNS



A flashing / beacon mode can be enabled from any brightness setting by holding both U and D low for at least 2 seconds. The LED will flash approximately 65 flashes (doublet flashes) per minute. The automatic shut-off feature is disabled while in the flashing / beacon mode. A special flashing pattern (described later) is used to indicate a low battery condition. To exit the flashing / beacon mode, U and D are taken high for at least 700 ms followed by low for approximately 1 second.

In the SOS mode the product will modulate the LED to produce the Morse Code for SOS. To enter the SOS mode the product must first enter the flashing / beacon mode described above, then U and D inputs must be high for at least 700 ms. The U and D inputs are then held low for more than 4 seconds. The automatic shut-off feature is disabled while in the SOS mode; low battery is not indicated in this mode. To exit the SOS mode, U and D inputs must be high for at least 700 ms followed by low for approximately 1 second.

Enabling and disabling the part does not clear the last mode or brightness setting. Only removal of power to the VDD pin and shorting VDD to GND for more than 10 ms assures a reset of the mode and brightness to default settings.

Design Considerations

Battery polarity is critical. Your product should provide a means to assure the correct polarity of voltage is applied at all times. Inadvertent reversal of battery polarity will damage the 904/905 parts. These parts will present a very low impedance with reversed polarity and could result in a product hazard when used with high-current battery technology.

Heat dissipation is through pins 1, 2, 3, 16, 17, 18 and the exposed Device Attachment Pin (DAP) in the middle of the package.

When the current through any pin is greater than 0.3A, the pin should be connected to a large trace / plane to dissipate the heat. The DAP should have multiple thermal paths to an exposed plane to remove the heat.

The boost/SEPIC regulator is designed to operate near boundary conduction mode. (Also referred to as borderline or critical conduction mode.) If the selected inductor is very large and the device is operating deeply into the continuous conduction mode, regulation at the LED may suffer.

The boost/SEPIC regulator combines pulse width modulation (PWM) and pulse frequency modulation (PFM) to adapt to the varying input and output conditions.

The regulator PWM operates with a period of 1.5 µs and a minimum off-time of 0.5 µs. In a boost configuration this limits the PWM output to less than 3 times the input voltage. (PFM is used for higher input to output ratios.) The minimum on-time is 0.25 µs. On-times less than 0.25 µs will trigger a transition to soft-start and / or fault mode.

The transition point between PWM and PFM is a 1.5 µs period with 0.5 µs off-time. When the time to charge the inductor is greater than 1 µs, the period is extended. Once the inductor is above its target current level, it is discharged for 0.5 µs in the PFM mode. The maximum on-time is 11 µs with a 11.5 µs period. This allows a boost ratio of over 20 to 1.

The temptation to use the largest inductance value that package and operating current can permit should be avoided. In the context of regulating the LED current, a large value inductor may result in greater ripple at the LED.

When the inductor is very large, the first period will be in the PFM mode since the charge time will be greater than 1 µs. It will then be followed by only 0.5 µs discharge time. For the next period, the on-time is approximately 0.5*(Vout - Vin)/Vin. This may result in an on-time less than 250 ns, and cause an extension of the period as described below. The large inductance value may cause the regulator to hunt between its start-up mode and normal mode.

After a few boost PWM cycles the LED current is above its target value and the boost converter is disabled. The remaining energy in the inductor is discharged to the output and will bring the LED voltage and current further above the target value. A very larger inductor will result in larger ripple at the LED.

At least 75% of the inductor energy should be discharged on each cycle, i.e., the peak inductor current should be more than 33% above the average inductor current. Larger inductor values will more than double the first period compared to the following periods and cause greater ripple at the output. More than 1/2 the inductor current needs to be discharged during the minimum 0.5 µs off-time.

For a 1.5 µs period and boost configuration operating with 0.25 µs on-time, the minimum output voltage should be 20% greater than the input. However, during start-up and when the output is operating near the input, the period is extended alternately from 1.5 µs to 2.5 µs. Under this scenario the first period has an off-time of 0.5 µs. It is followed by an on-time of less than 0.25 µs with a 2.5 µs period (>2.25 µs off time). If the output, including the rectifying diode drop, is 11% greater than the input, the device will not enter a fault mode. Large inductor values can cause hunting between 1.5 and 2.5 µs even at outputs greater than 20% of the input.

The fault mode is entered if two consecutive periods experience an on-time of less than 0.25 µs. Under fault conditions, the period is extended to 11.5 µs and will remain at 11.5 µs until the on-time is greater than 0.25 µs.

Continuous 11.5 µs faults will disable the device because the inductor is assumed to be shorted.

If the on-time is greater than 0.25 µs, the current period is reduced to either 1.5 µs for PWM operation or the normal PFM period of 0.5 µs longer than the inductor charge time.

The shortest on-time is 70 ns, which is set by the leading edge blanking interval.

The VCC pin provides the gate drive voltage for the power FET's. When the battery voltage may be less than 3 volts, use a bootstrap method to couple the inductor output voltage back to VCC pin (up to 6.5 volts). This will minimize the on resistance of the FET's and is especially important when using only 2 alkaline batteries near end-of-life, which will not be sufficient to drive the power FET's for high current operation, but will be only sufficient for the bootstrap start up.

The 904 and 905 have the ability to drive external power FETs in parallel with the internal FETs. The gate drives at BG and LG pins are enabled when EGE is tied to GNDG. EGE does not have a pull-up current source, so do not let this pin float. To disable BG and LG, tie EGE to VCC. When disabled, BG and LG are high impedances to GNDG. However, there are internal diodes from BG/LG to VCC and GNDG.

The current sensing point is internal to the part and consequently there is resistance between the sensing point and the pin-board interface. When calculating the external sense resistance, adjustment should be made for the sense offset resistance.

Over voltage protection (OVP) is required. The OVP pin with a resistor network is used to protect both the LED and the 904 / 905 FETs from a brief or intermittent open-circuit. Without OVP, an open-circuit will cause the regulator to continuously run and increase the LED voltage until device breakdown and damage occurs in the part.

The OVP network voltage should be set at least 0.3 volts greater than the maximum operating voltage of the LED to allow for the sense voltage and the voltage drop across the LED regulator FET.

The current flowing in the OVP resistor network should be minimized to prevent dimming of the LED during the flashing beacon mode; using less than 1/5000 of the full brightness LED current will prevent noticeable dimming.

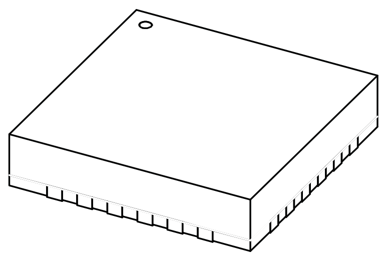
The FET that drives the LED is very fast. Stray lead inductance from the LED to the FET may cause excess voltage and damage to the LD pin. This phenomena has been observed with 6 inch leads between the LD pin and the LED. To protect the LD pin from electrical overstress, a schottky diode (D1) from LD to the output of the regulator is highly recommended.

As mentioned before, the mode and brightness values are retained as long as power is provided to the VDD pin. The minimum operating voltage is 1.8 volts; operating below this voltage is possible with degraded performance, but is not recommended. As the voltage on VDD is reduced, the voltage references degrade, internal amplifiers and comparators stop working around 1.6 volts, the internal oscillator stops working around 1.4, and then the pull-up currents fail. However, the logic inside the part will typically retain its state with VDD as low as 0.8 volts and only consume nano Amperes.

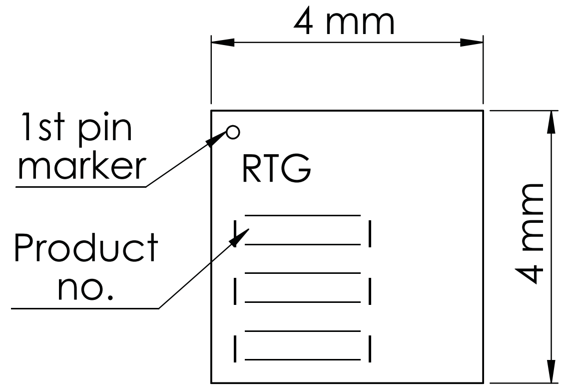
It is important to set the low-battery shut-off point for the end-product at or above 1.8 volts. Significantly below 1.8 volts, the 904 / 905 part may stop operating in an indeterminate state.

Removing the battery to remove power from VDD may not be an effective way to "reset" the part. The reverse leakage through the boost rectifier from the output capacitor may provide enough energy to retain the logic content of the part. To assure a clearing of the logic, the voltage on VDD must be brought to less than 10 mV for more than 10 ms. When using a large filter capacitor, the very slow discharge rate may leave the part in an unstable state as VDD transitions from 1.2 to 0 volts. To assure clearing of the logic state, a bleed resistor in parallel with VDD will be required.

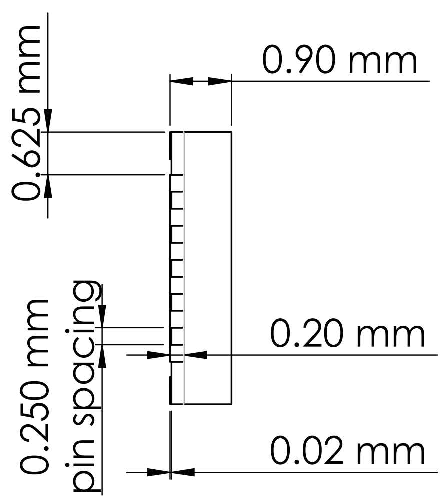
QFN—4X4—24 ld



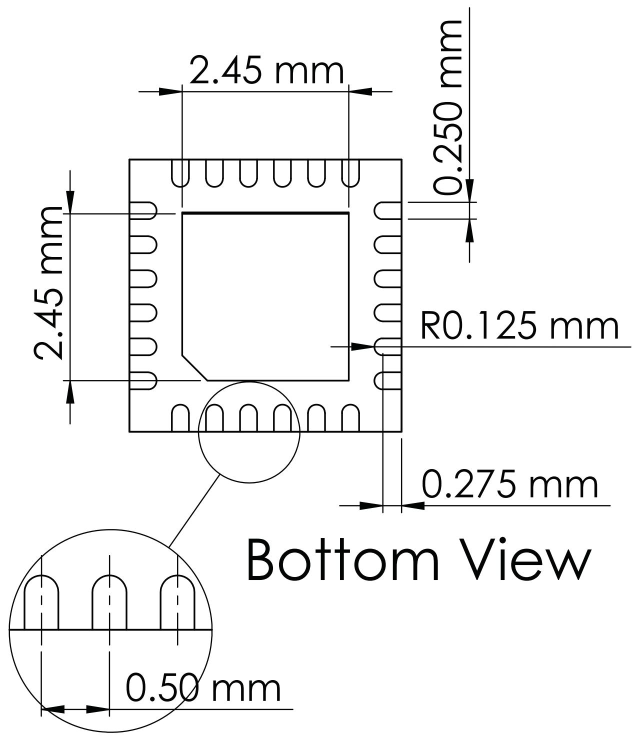
Trimetric View
6 pins per side



Top View



Side View



Bottom View

Detail C
Pitch