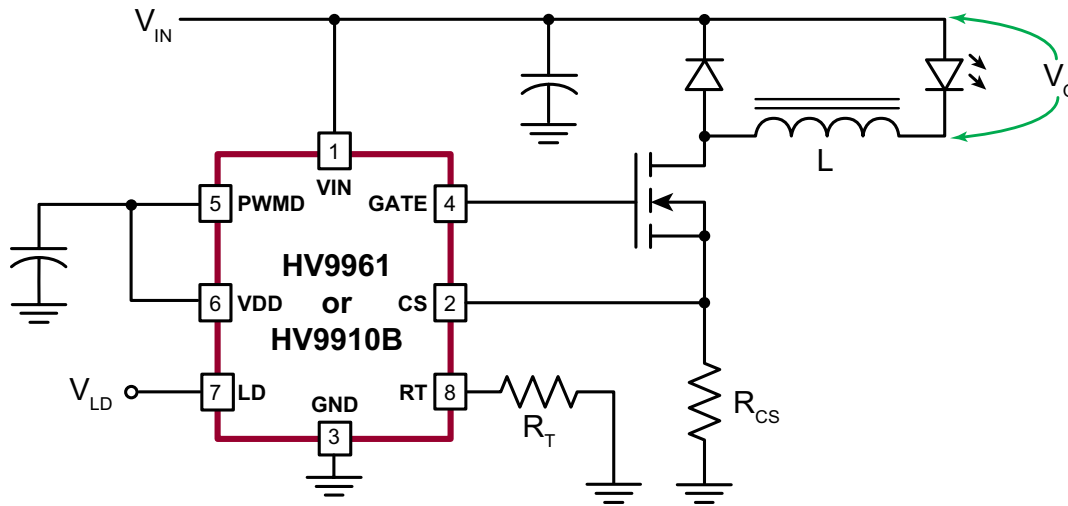


Compatibility and Functional Differences between the HV9961 and HV9910B LED Drivers

Figure 1. Typical application circuit of HV9910B and HV9961.



Peak-Current Control vs. Average-Mode Current Control

Peak-current control of a buck converter used in the HV9910B, while being the most economical and simplest way to regulate the LED current, suffers accuracy and regulation problems. These problems arise from the so-called peak-to-average current error, contributed by the current ripple in the output inductor and by the propagation delay in the current sense comparator.

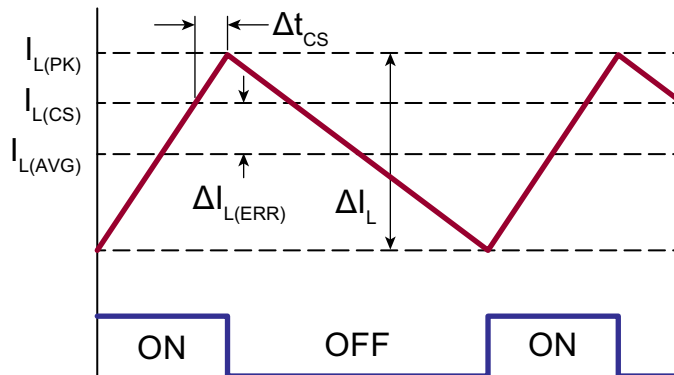
The peak-to-average current error $\Delta I_{L(ERR)}$ is inherent to the HV9910B, since the IC is controlling the peak inductor cur-

rent $I_{L(PK)}$, whereas the intent is to regulate the average current $I_{L(AVG)}$. The difference between the two currents equals one-half of the inductor current ripple ΔI_L , which can be expressed by the following equation:

$$\frac{1}{2} \Delta I_L = \frac{V_O t_{OFF}}{2L} \tag{1}$$

In this equation, V_O is the LED voltage, t_{OFF} is the off-time of the GATE output of the HV9910B (the lower waveform in Fig.2), and L is the inductance value. Note that all parameters in right side of Equation 1 can vary from one part to another and depend on the operating temperature.

Figure 2. Peak-to-average current error produced by the peak-current control method of HV9910B.



Another source of error produced by a peak-current controller such as the HV9910B is associated with the current-sense comparator delay Δt_{CS} . The actual peak current $I_{L(PK)}$ is higher than the comparator threshold reference $I_{L(CS)}$ because of this propagation delay. Therefore, the total peak-to-average error can be expressed as:

$$\Delta I_{L(ERR)} = \frac{V_{O}t_{OFF} - 2V_{IN}\Delta t_{CS}}{2L} \quad (2)$$

where V_{IN} is the input DC power supply voltage.

As one could see from Equation 2, the average inductor current $I_{L(AVG)}$ also suffers poor load and line regulation, since it is dependent on the input voltage V_{IN} and the output voltage V_O .

Lastly, there is a significant part-to-part variation in the LED current that occurs due to the CS input offset voltage V_{OS} . Although this offset voltage is only $\pm 25mV$ at $-40^\circ C < T_A < +85^\circ C$, it contributes as much as $\pm 10\%$ variation of the LED current even at the maximum CS threshold voltage of 250mV.

The HV9961 overcomes the above drawbacks by means of Supertex's average-mode constant current control method. The IC regulates the average inductor current $I_{L(AVG)}$ directly and accurately within $\pm 3\%$ over a wide GATE duty cycle range of at least $0.1 < D < 0.75$. It also includes an auto-zero circuit at the CS input that cancels the propagation and offset errors.

Linear Dimming

When the LD voltage is $V_{LD} \geq 1.5V$, the output LED current is simply programmed with the HV9961 as:

$$I_{L(AVG)} = \frac{272mV \pm 3\%}{R_{CS}} \quad (3)$$

where 272mV is the internally fixed reference voltage. Otherwise:

$$I_{L(AVG)} = \frac{V_{LD} \pm 3\%}{5.5 \cdot R_{CS}} \quad (4)$$

Unlike the HV9910B, which has the LD range from 0 to 0.25V, the active LD input voltage range of the HV9961 is from 0 to 1.5V. Moreover, for the HV9910B, $V_{LD} = GND$ does not produce $I_{LED} = 0A$ due to the D_{MIN} limitation. There is always some residual LED current remaining despite connecting LD to GND. The HV9961 overcomes this issue by disabling the GATE output when $V_{LD} < 150mV$. The GATE switching resumes when $V_{LD} > 200mV$.

Note that the latter feature of the HV9961 allows a mixed-mode PWM/linear dimming mode. A single square-wave input signal can be applied at LD, where both the signal duty cycle and its amplitude are modulated in order to expand the dimming range.

Figure 3. Typical output voltage regulation characteristic of LED current.

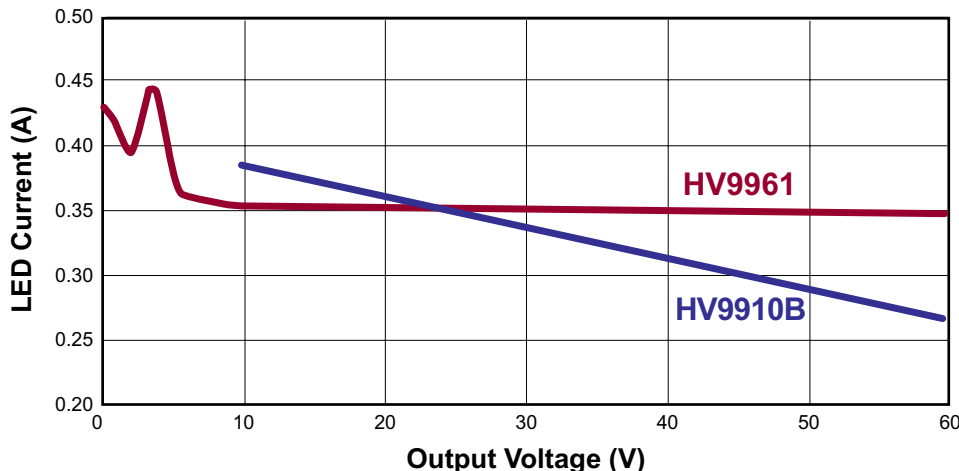
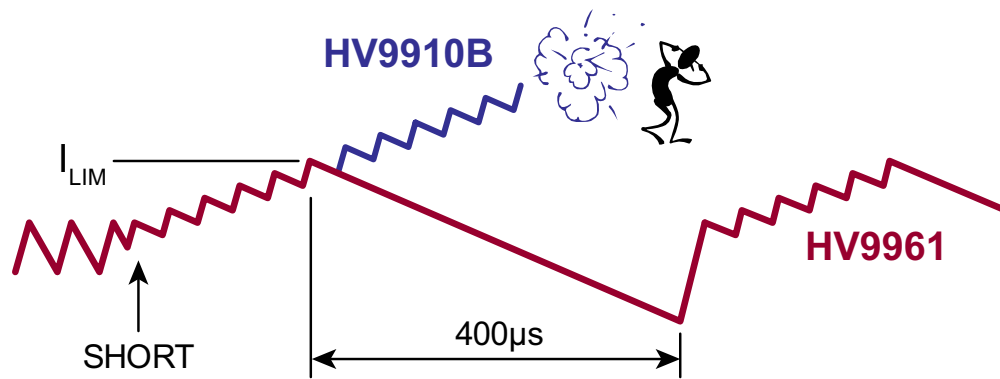


Figure 4. Effect of the output short circuit on the inductor current.



Short-Circuit Protection

Both the HV9910B and HV9961 are characterized by a minimum on-time of the GATE output. This minimum on-time includes the leading-edge blanking delay and the current-sense comparator propagation delay. The minimum on-time is 0.47µs(max) for the HV9910B and 1.0µs(max) for the HV9961. When a short circuit is applied at the output of the buck converter, the only voltage available to reset the magnetic flux in the inductor during t_{OFF} is the rectifier diode voltage drop. When the converter keeps switching at the same frequency rate this may not be enough. Therefore, the inductor current will keep rising every switching cycle. (See Figure 4.)

The HV9961 is protecting the LED driver from such “staircase” saturation of the inductor by introducing a second threshold $I_{LIM} = 0.44V/R_{CS}$. When this threshold is reached, the GATE output becomes disabled for 400µs, thus letting the inductor current ramp down to a safe level.

Constant-Frequency and Constant Off-Time Operating Modes

The HV9910B can be configured for operating in either switching mode. When R_T is connected to GND, it maintains a constant switching frequency. Wiring R_T to GATE yields a fixed t_{OFF} mode. The corresponding timing equations are:

$$t_{OSC} = 40pF \cdot R_T + 0.88\mu s \quad (5a)$$

$$t_{OFF} = 40pF \cdot R_T + 0.88\mu s \quad (5b)$$

where t_{OSC} is the switching period with R_T wired to GND, and t_{OFF} is the off-time with R_T connected to GATE.

The HV9961 does not support the fixed frequency mode. Moreover, the R_T resistor must be wired to GND in all cases.

Therefore, the HV9961 cannot be used as a direct drop-in replacement in the applications of the HV9910B wired for the fixed t_{OFF} operation, and a layout change is required. The HV9961 t_{OFF} is given by:

$$t_{OFF} = 40pF \cdot R_T + 0.3\mu s \quad (5c)$$

If the HV9910B is wired for the fixed frequency operation, the conversion to the HV9961 will merely require the R_T resistor value change. Since $t_{OFF} = (1 - V_O / V_{IN}) \cdot t_{OSC}$, Equations 5a and 5c can be solved for the new R_T value:

$$R_{T(HV9961)} = \left(1 - \frac{V_O}{V_{IN}}\right) \cdot (R_{T(HV9910B)} + 22k\Omega) - 7.5k\Omega \quad (6)$$

Duty Cycle Range

The duty cycle is determined by the equation $D = t_{ON} / t_{OSC} = t_{ON} / (t_{OFF} + t_{ON})$. Both the HV9910B and the HV9961 have their minimum duty cycle D_{min} limited by the minimum on-time. However, with the HV9961 the guaranteed $\pm 3\%$ accuracy of the LED current can only be achieved with the duty cycle $D_{min} > 0.08 \sim 0.1$.

The maximum duty cycle of the HV9910B operating with the fixed frequency is limited to $D_{max} = 0.5$. Exceeding $D = 0.5$ with this operating mode causes sub-harmonic oscillation at $1/2$ of the switching frequency. When the HV9910B is operated with fixed t_{OFF} , there is no theoretical limit of D_{max} . However, due to parasitic resistances in the circuit and large switching frequency variation, it is not recommended that a $D_{max} = 0.8$ be exceeded with this operating mode.

With the HV9961, regulation of the average inductor current is limited to $D_{max} \leq 0.75$. When $D = 0.75$ (125°C) or $D = 0.8$ (105°C) is exceeded, the functionality of the HV9961 will begin approaching that of the HV9910B, and the LED current will drop accordingly.

Table 1. Functional comparison of HV9910B and HV9961.

Feature	HV9910B	HV9961
Fixed-Frequency Mode	Resistor from RT to GND	N/A
Fixed Off-Time Mode	Resistor from RT to GATE	Resistor from RT to GND (value adjustment needed for conversion from HV9910B)
Current Threshold	250mV or V_{LD} (peak)	272mV or $V_{LD}/5.5$ (average)
Current Threshold Accuracy	10%	Auto-zero
LED Current Accuracy	Depends on inductance and switching frequency variation	Independent of inductance and switching frequency variation
LED Current Regulation	Poor. LED current depends on input and output voltage	Good
LD Input Range	0 to 250mV	0.2V(0.15V) to 1.5V
Residual LED Current at $V_{LD} = GND$	5% (typ.) of I_{LED} @ $V_{LD} = 250mV$	0A
Current Limit Threshold	none	440mV
Hiccup Time	N/A	400 μ s
Minimum On-Time	465ns	1000ns
Maximum Duty Cycle	0.5 (fixed freq.), 0.8 (fixed T_{OFF})	0.75

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