LITIX™ Basic+ LED driver family

How to implement a rear combination lamp

About this document

Scope and purpose

This document explains the main operating principles of the pulse width modulation (PWM) engine integrated in the LITIX™ Basic+ family and how to build a rear combination lamp (RCL) with the use of it. The related component dimensioning process and configuration possibilities are described.

Intended audience

HW designers, LED system architects and engineers for LED lighting applications

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1 Rear combination lamp (RCL)

A rear combination tamp (RCL) is composed of a tail (position) and a stop (brake) light function; the two functions have different light intensity and usually share the same LEDs. Typically for the tail function only a small percentage, ~10%, of the intensity of the stop function is required. For the implementation of an RCL module it is common to use a pulse width modulation (PWM) signal to achieve the required two levels of light intensity (Figure 1).

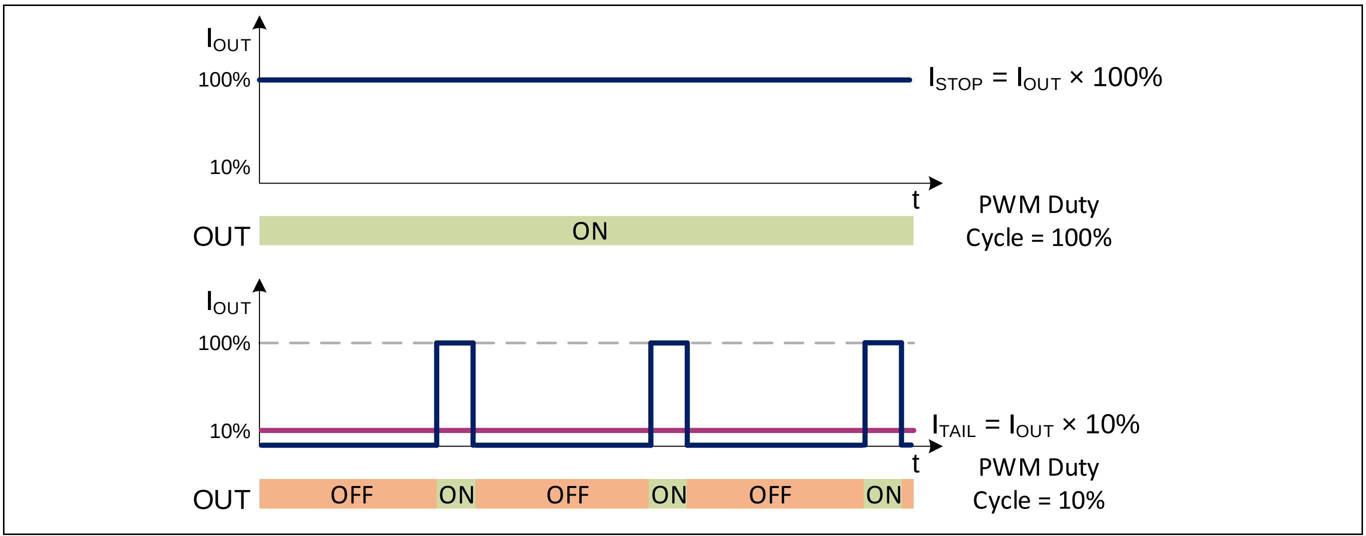

Figure 1 PWM signal used to implement two levels of light intensity

The LITIX™ Basic+ LED driver family offers a group (high end group) of three devices, TLD2142-1EP (1 in/1 out), TLD2252-2EP (2 in/2 out) and TLD2141-3EP (1 in/3 out) equipped with an integrated PWM engine that makes them ideal for an easy and cost effective implementation of an RCL module.

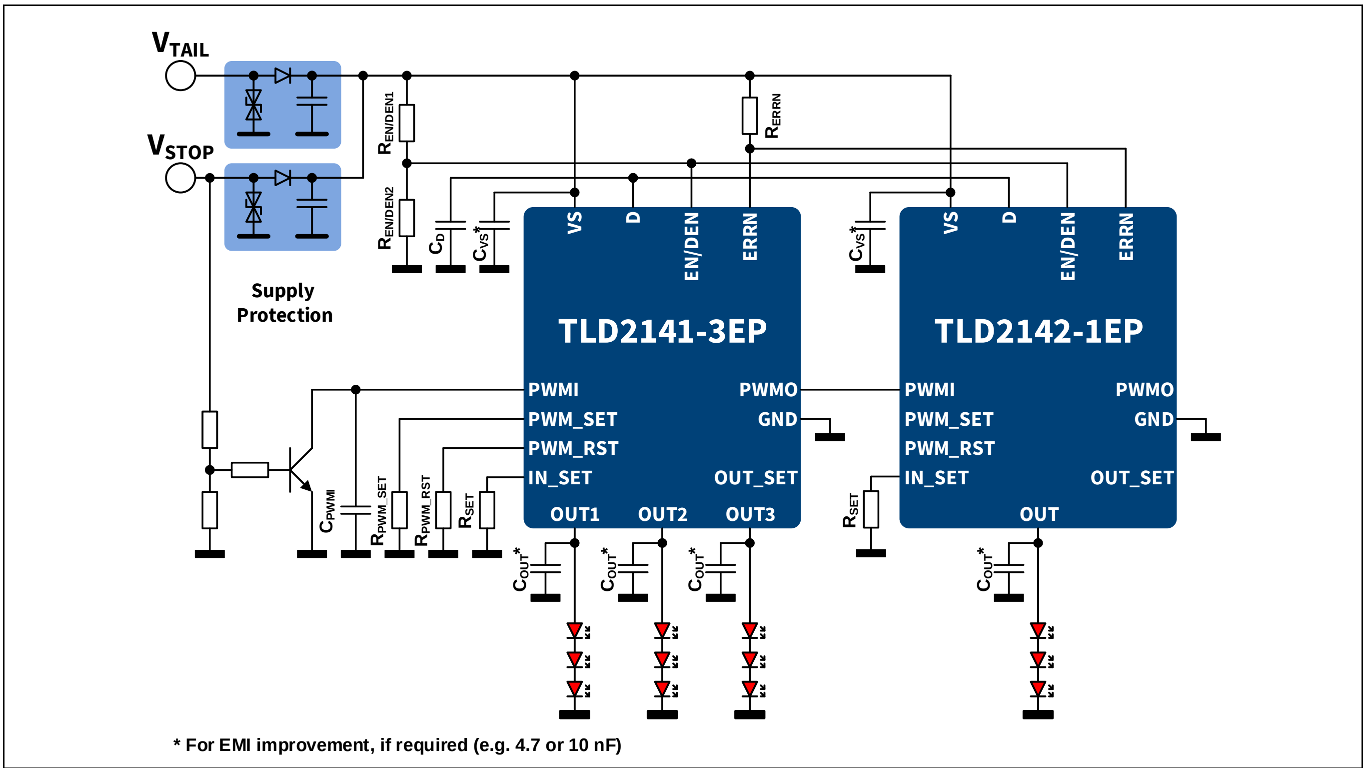

Figure 2 Rear Combination Lamp implemented with LITIX™ Basic+ TLD2141-3EP and TLD2142-1EP

2 Pulse width modulation (PWM) engine in LITIX™ Basic+

The PWM engine operating principle is based on the cyclic charging and discharging of a capacitor connected to the PWMI pin, C_{PWMI}, as shown in Figure 3. The charging and discharging of the C_{PWMI} capacitor is done with constant and precise currents, I_{PWM_SET} and I_{PWM_RST}, set by the two resistors connected to the PWM_SET and PWM_RST pins. The PWM_SET and PWM_RST pins feature a fixed reference voltage, regulating at 1.22 V (data sheet parameters P_8.4.12 and P_8.4.13) which is used to create two reference currents, I_{PWM_SET} and I_{PWM_RST}, using the R_{PWM_SET} and R_{PWM_RST} resistors respectively. The currents flowing through the PWM_SET and PWM_RST pins are mirrored and sourced to the PWMI pin in order to charge and discharge the capacitor C_{PWMI} with typically 1 V amplitude from typically 1.7 V to 2.7 V (data sheet parameters P_8.4.1 and P_8.4.2), as shown is Figure 5.

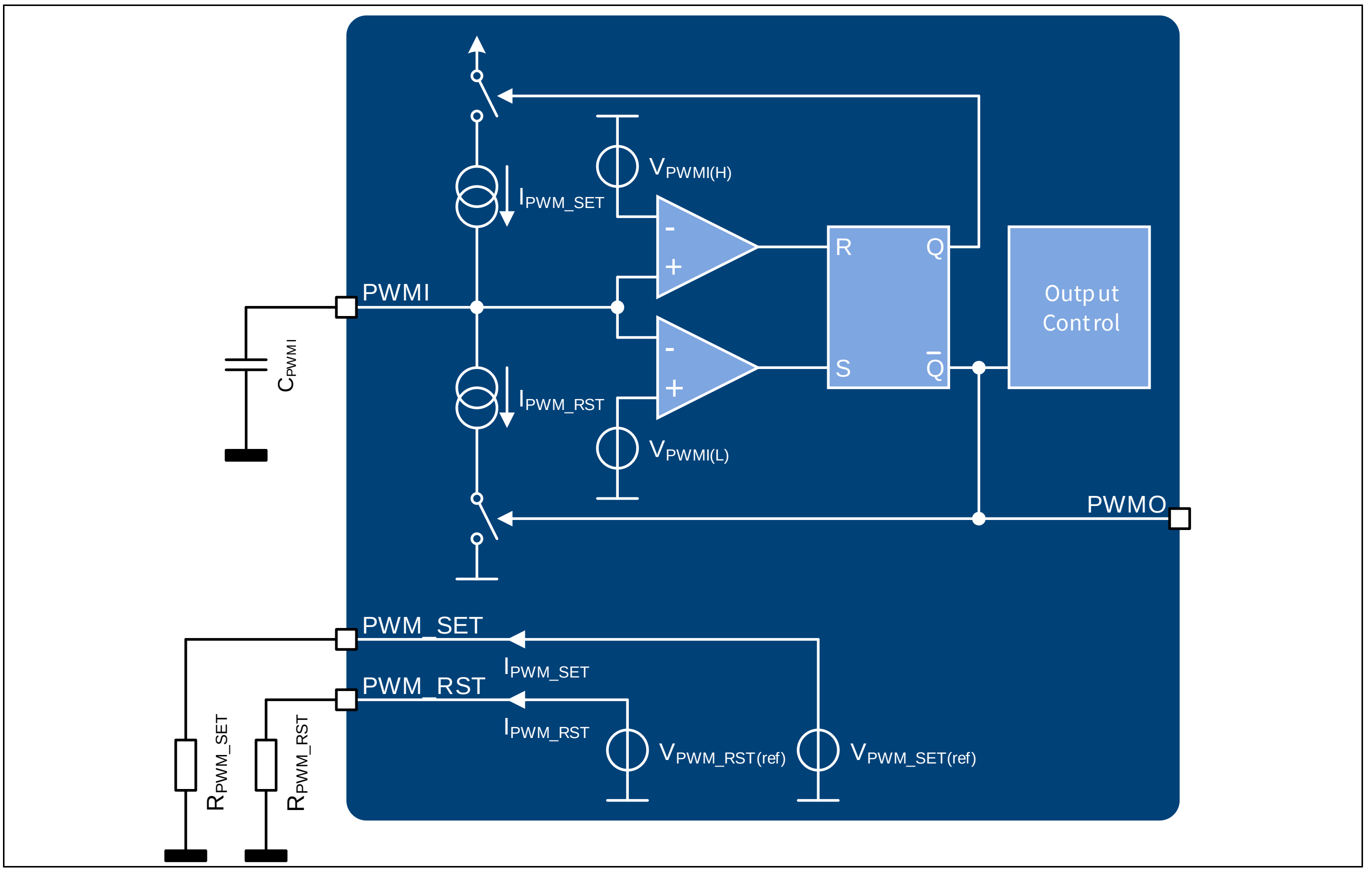

Figure 3 PWM unit concept diagram (including PWMO drive and typical external circuitry) for TLD2142-1EP and TLD2141-3EP

Contrary to the TLD2142-1EP and TLD2141-3EP, the TLD2252-1EP output control is decoupled from the PWM unit (Figure 4). Therefore, the PWMO pin is used to externally synchronize the two output channels. This gives more design flexibility as the two channels can be individually synchronized to the PWM engine, allowing only one channel to be controlled by the PWM unit or even to use the PWM unit as a general purpose timer engine to drive other external circuits or other LITIX™ Basic or LITIX™ Basic+ devices.

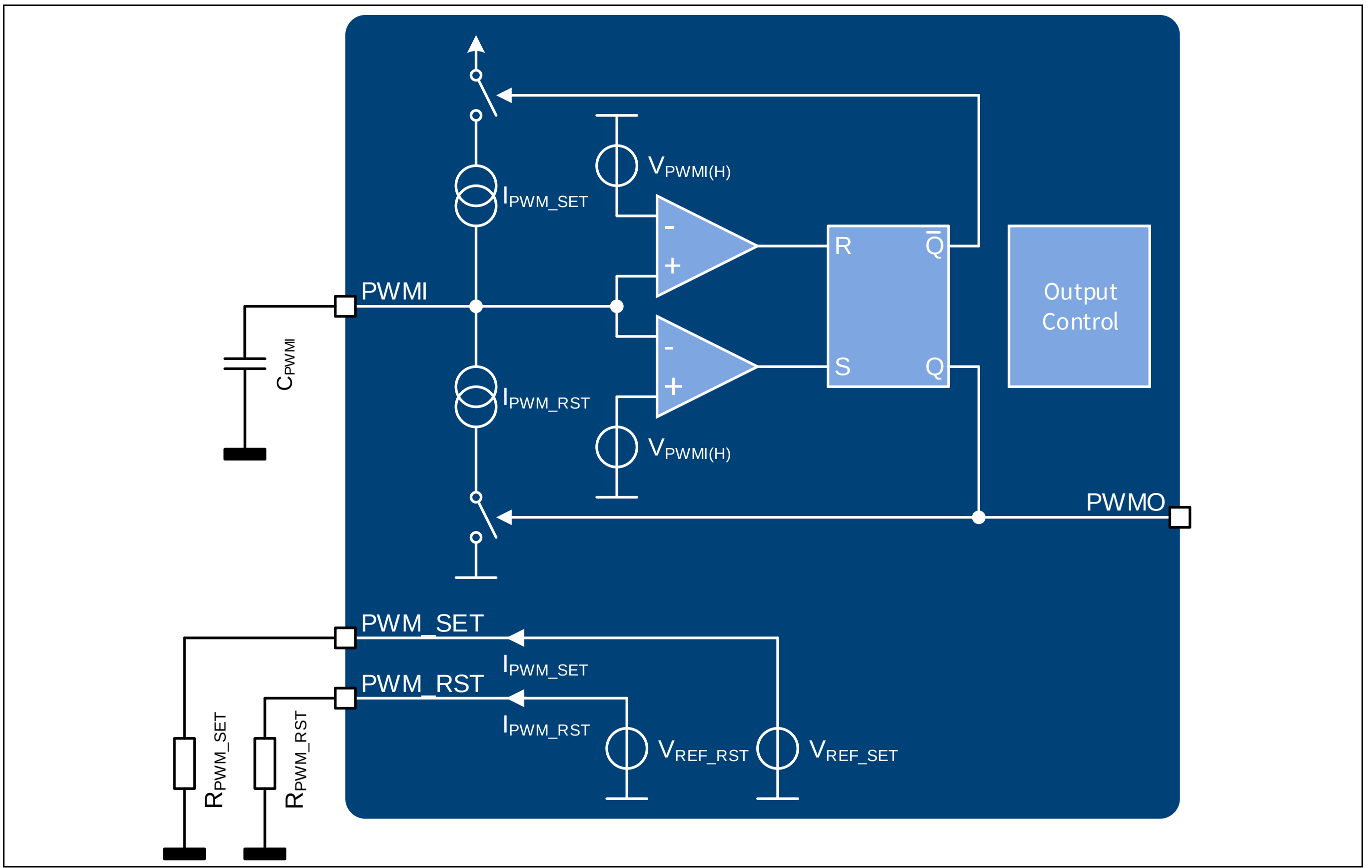

Figure 4 PWM unit concept diagram (including PWMO drive and typical external circuitry) for TLD2252-2EP

Figure 5 depicts the charging and discharging phases defined by the external components and the internal PWM unit.

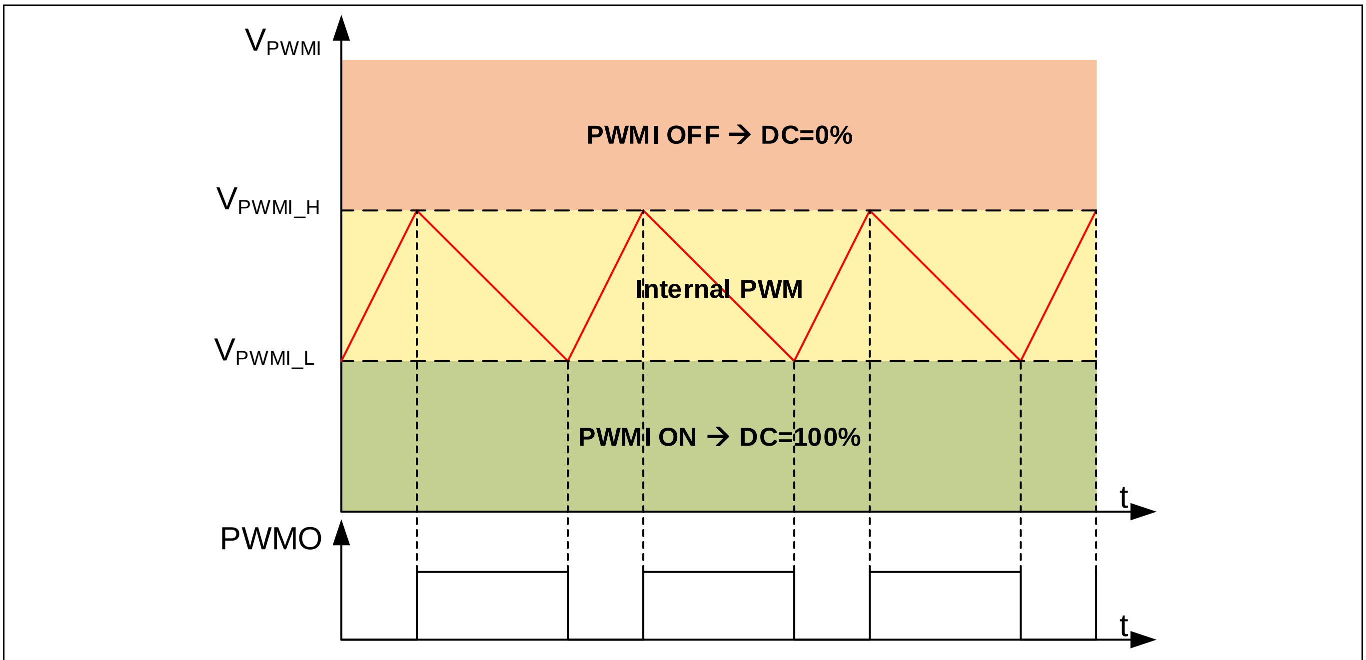

Figure 5 PWMI operating voltages and timing

Due to the constant current charging approach, the duty cycle is exclusively dependent on the ratio of the charging and discharging currents.

2.1 Calculation of C_{PWMI}, R_{PWM_SET} and R_{PWM_RST}

The PWM frequency and duty cycle can be calculated using the electrical characteristics defined in Table 9 of the datasheet and the equations (2.1.1) – (2.1.4) below:

$$t_{PWM(ON)} = \frac{C_{PWMI}}{I_{PWM\_SET}}\left(V_{PWMI(H)} - V_{PWMI(L)}\right) = \frac{R_{PWM\_SET}C_{PWMI}}{V_{REF\_SET}}\left(V_{PWMI(H)} - V_{PWMI(L)}\right) \quad (2.1.1)$$

$$t_{PWM(OFF)} = \frac{C_{PWMI}}{I_{PWM\_RST}}\left(V_{PWMI(H)} - V_{PWMI(L)}\right) = \frac{R_{PWM\_RST}C_{PWMI}}{V_{REF\_RST}}\left(V_{PWMI(H)} - V_{PWMI(L)}\right) \quad (2.1.2)$$

$$f_{PWMI} = \frac{1}{t_{PWMI(ON)} + t_{PWMI(OFF)}} = \frac{V_{REF_{SET}/RST}}{V_{PWMI(H)} - V_{PWMI(L)}} * \frac{1}{(R_{PWM\_SET} + R_{PWM\_RST}) * C_{PWMI}} \quad (2.1.3)$$

$V_{PWMI(L)}$ = 1.7 V and $V_{PWMI(H)}$ = 2.7 V (data sheet parameters P_8.4.1 and P_8.4.2 respectively).
$V_{REF\_SET/RST}$ = $V_{PWM\_SET(ref)}$ = $V_{PWM\_RST(ref)}$ = 1.22 V (parameters P_8.4.12 and P_8.4.13 of data sheet).

$$DC_{PWMI} = \frac{t_{PWMI(ON)}}{t_{PWMI(ON)} + t_{PWMI(OFF)}} = \frac{R_{PWM\_SET}}{R_{PWM\_SET} + R_{PWM\_RST}} \quad (2.1.4)$$

As shown in equations (2.1.1) and (2.1.2), the on time, $t_{PWM(ON)}$, of the PWM signal is dependent on the I_{PWM_SET} current while the off time, $t_{PWM(OFF)}$, is dependent on the I_{PWM_RST} current. The selection of I_{PWM_SET} and I_{PWM_RST} reference currents depends on the duty cycle, the frequency and the capacitance range that will be used. In order to properly set the I_{PWM_SET} and I_{PWM_RST} currents, the resistors R_{PWM_SET} and R_{PWM_RST} have to be selected so that the currents flowing through the PWM_SET and PWM_RST pins don't exceed the absolute maximum rating (data sheet parameters P_4.1.28 and P_4.1.29).

The LITIX™ Basic+ devices are optimized in the duty cycle range of 10% to 90%. Table 1 shows the I_{PWM_SET} and I_{PWM_RST} currents' limits in which optimized behavior can be achieved.

Table 1 I_{PWM_SET} and I_{PWM_RST} limits based on the selected duty cycle

PWM Duty cycle	I_{PWM_SET}	I_{PWM_RST}
10%	270 µA	30 µA
90%	30 µA	270 µA

The duty cycle range can be further extended to 5% to 95% by adapting the resistors R_{PWM_SET} and R_{PWM_RST} and therefore adapting the I_{PWM_SET} and I_{PWM_RST} reference currents.

For the dimensioning of the PWM components it is best to start from the highest used current I_{PWM_SET} or I_{PWM_RST}. Therefore, in an application where the requested duty cycle is low (DC < 50%), the I_{PWM_SET} current is first defined and then the R_{PWM_SET}, R_{PWM_RST} and C_{PWMI} can be calculated. Likewise, in an application where the requested duty cycle is high (DC > 50%), the I_{PWM_RST} current is defined first. Table 2 shows the simplified formulas for the calculation of R_{PWM_SET} and R_{PWM_RST} based on the selected duty cycle.

Table 2 Simplified calculation formulas of R_{PWM_SET} and R_{PWM_RST} based on selected duty cycle

Duty cycle	R_{PWM_SET}	R_{PWM_RST}
D < 50%	$R_{PWM\_SET} = \frac{V_{REF_{SET}/RST}}{I_{PWM_{SET}}}$	$R_{PWM\_RST} = R_{PWM\_SET} * \frac{1-D}{D}$
D = 50%	$R_{PWM\_SET} = \frac{V_{REF_{SET}/RST}}{I_{PWM_{SET}/RST}}$	$R_{PWM\_RST} = \frac{V_{REF_{SET}/RST}}{I_{PWM_{SET}/RST}}$
D > 50%	$R_{PWM\_SET} = R_{PWM\_RST} * \frac{D}{1-D}$	$R_{PWM\_RST} = \frac{V_{REF_{SET}/RST}}{I_{PWM_{RST}}}$

Another approach to calculate the reference currents, which can only be used when the duty cycle is in the range of 10% - 90%, is described below. In this range the two reference currents, I_{PWM_SET} and I_{PWM_RST} are complementary:

$$I_{PWM\_SET} + I_{PWM\_RST} = 300\ \mu A \tag{2.1.5}$$

Table 3 shows the simplified calculation formulas for dimensioning the R_{PWM_SET} and R_{PWM_RST} resistors and the respective reference currents.

Table 3 Simplified calculation formulas of reference currents and respective resistors when duty cycle is 10% - 90%

Pin	Reference current	Resistor
PWM_SET	$I_{PWM\_SET} = 300\ \mu A * (1-D)$	$R_{PWM\_SET} = \frac{V_{PWM\_SET}}{300\ \mu A * (1-D)}$
PWM_RST	$I_{PWM\_RST} = 300\ \mu A * D$	$R_{PWM\_RST} = \frac{V_{PWM\_RST}}{300\ \mu A * D}$

2.2 Frequency and duty cycle limitations

The PWM frequency can be configured within the range of 100 Hz to 1 kHz. It is mainly limited by the human eye so that flickering would not be observed at the application.

On the other hand, the duty cycle is limited by the PWMI turn on time, $t_{ON(PWMI)}$, and the PWMI turn off time, $t_{OFF(PWMI)}$ (data sheet parameters P_6.6.12 and P_6.6.13).

When selecting the duty cycle, the actual turn-on time for the respective application needs to be considered. This is given by the equation (2.2.1):

$$Actual\ t_{ON} = t_{ON} - t_{ON(PWMI)} - t_{OFF(PWMI)} \tag{2.2.1}$$

Therefore, in an application where the PWM frequency is 400 Hz and the required PWM duty cycle is 5%, the actual turn-on time of the LEDs would be:

$$t_{PWMI} = \frac{1}{f_{PWMI}} = \frac{1}{200\ Hz} = 2.5\ msec \tag{2.2.2}$$

$$t_{ON} = t_{PWMI} * DC = 125\ \mu sec \tag{2.2.3}$$

$$Actual\ t_{ON} = t_{ON} - t_{ON(PWMI)} - t_{OFF(PWMI)} = 125\mu sec - 15\mu sec - 10\mu sec = 100\ \mu sec \tag{2.2.4}$$

Note: *This is worst case calculation as the actual turn on and turn off times, $t_{ON(PWMI)}$ and $t_{OFF(PWMI)}$, are significantly faster.*

Figure 6 shows the output activation delay based on the PWMI turn on and off times:

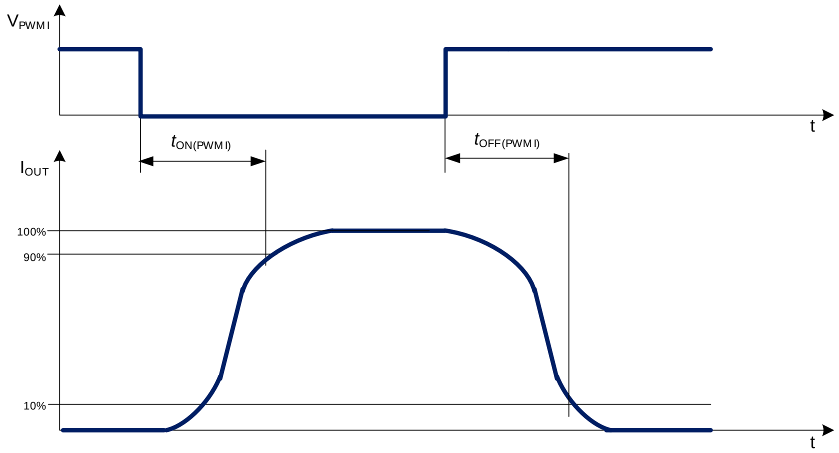

Figure 6 PWMI turn on and off timing diagram

In addition to the PWMI turn on and off times, when selecting the duty cycle, the fault to ERRN activation delay, t_{fault} (data sheet parameter P_7.5.19) needs to be considered as well, since adequate time to detect and report a fault if present must be ensured.

In the above example, where the actual turn-on time is 100 µsec, the device will not have the required time to detect the presence of a fault in all cases as the maximum time for fault detection and ERRN activation, t_{fault} (data sheet parameter P_7.5.19), is approximately 150 µsec.

2.3 Direct control of PWMI

PWMI input can also be controlled by the PWMO output of another LITIX™ Basic+ device or alternatively, a push-pull output stage of a microcontroller: the host device decided the digital dimming characteristics by applying the proper control cycle in order to set the on/off timing, according to the chosen dimming function.

The PWM engine drives the internal channels of TLD2142-1EP and TLD2141-3EP (Figure 3) and via PWMO output pin it can also be used to synchronize other devices. On the contrary, the engine doesn't drive directly the internal channels of the TLD2252-2EP (Figure 4) and so the PWMO output pin can be used to synchronize both output channels as well as other LITIX™ Basic+ devices.

2.3.1 TLD2252-2EP PWMO feedback circuitry

The LITIX™ Basic+ TLD2252-2EP outputs are decoupled from the PWMI pin state (Figure 4) and therefore an additional PWM signal feedback is necessary. The signal from PWMO pin may be fed back to the IN_SET pins, used to activate/deactivate the IN_SET current. In PWM off-time, the IN_SET current is reduced to zero and in the on-time it is defined by the R_{SETx}.

There are two ways to feed the PWMO signal back to the IN_SET pins, as shown in Figure 7.

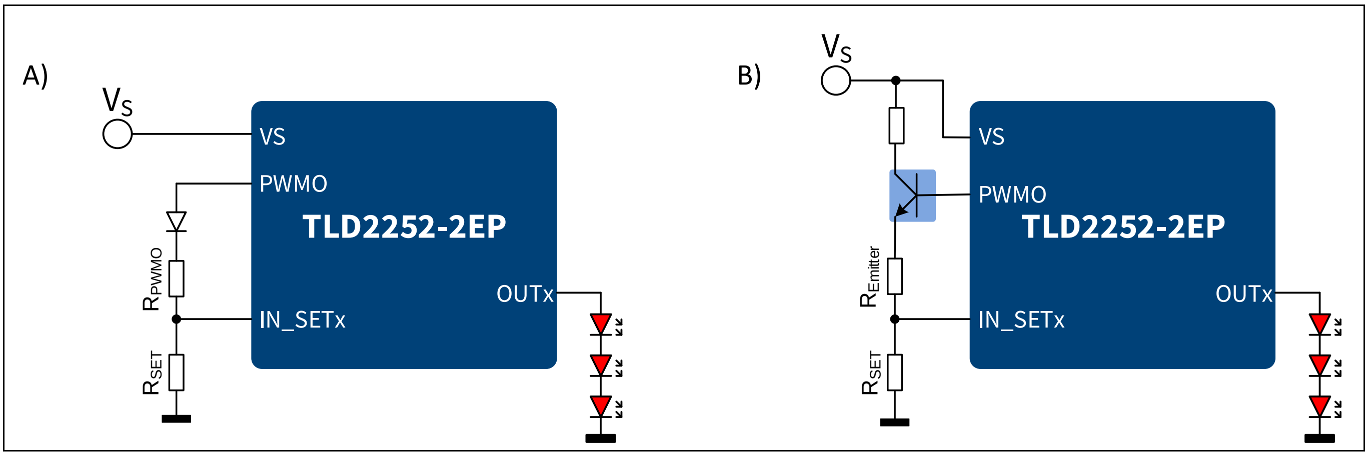

Figure 7 PWMO feedback circuitry

The first way is to connect the PWMO signal back to the IN_SET pin using a diode and a small optional resistor (similar size to the R_{SET}) to limit the current consumption (Figure 7A). So, when PWMO = 5 V, the voltage at IN_SET pin, V_{IN_SET} must be higher than the reference voltage $V_{IN\_SET(ref)}$ (data sheet parameter P_6.6.1). This limits the maximum value of R_{PWMO}. The minimum voltage at IN_SET pin so that no current flows through the outputs is 2 V. The PWMO current consumption is then given by the following formula:

$$I_{PWMO} = \frac{(5V - V_f)}{(R_{SET} + R_{PWMO})} \quad (2.3.1.1)$$

In case several devices are connected to the same PWMO pin, the current consumption can be too big compared to the pull-up strength of the PWMO pin. As this pull-up current needs to be shared between all connected devices and a margin for a fast enough transition is needed, an NPN transistor based solution can be used (Figure 7B). Here, the pull-up of the IN_SET voltage level is done by the transistor which is connected to V_S. The current consumption from the PWMO pin is given by the formula:

$$I_{PWMO} = \frac{I_{CE}}{\beta} = \frac{\frac{(5V - V_{BE})}{(R_{SET} + R_{Emitter})}}{\beta} \quad (2.3.1.2)$$

For the rest of the LITIX™ Basic+ devices which are connected to the PWMO signal, there is no need for a special feedback circuitry as the state of the PWMI pin is directly reflected at the output stage (Figure 3). This means that the PWMI pin of LITIX™ Basic+ device can be directly connected to the PWMO pin of a TLD2252-2EP. The PWMI pin of Basic+ device with no integrate PWM engine features a pull-up current of typically 50 µA ± 20 µA. This pull-up current is added to pull-up the low active PWMI pin in case it is unconnected to safely disable the power stage.

2.3.2 Maximum number of LITIX™ Basic+ devices driven by one PWMO pin

PWMO has the capability of synchronizing not only one additional LITIX™ Basic+ device but several.

The devices without PWM engine have a pull-up current of typically 50 µA ± 20 µA, as shown in Figure 8. In the high end devices, this pull-up current is present when the PWM_RST pin is left open.

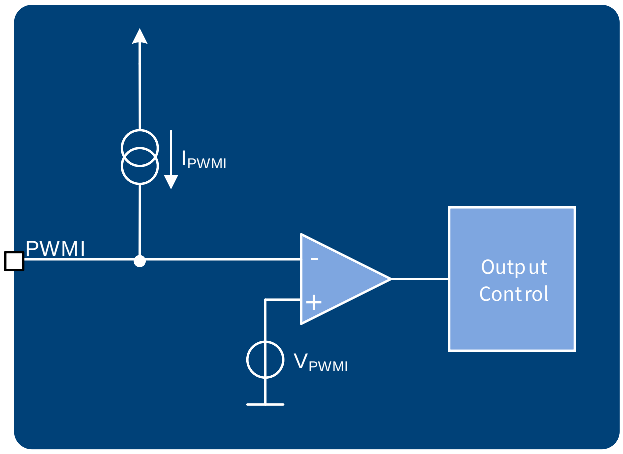

Figure 8 PWMI pin block diagram (variants without PWM engine)

Taking as reference the PWMO on pull-down current, $I_{PWMO(ON)}$ (data sheet parameter P_8.4.15), the maximum number of allowed devices is calculated as follows:

$$Maximum\ number\ of\ devices = \frac{I_{PWMO(ON)}}{I_{PWMI}} = \frac{750\mu A}{70\mu A} = {\sim}10\ devices \tag{2.3.2.1}$$

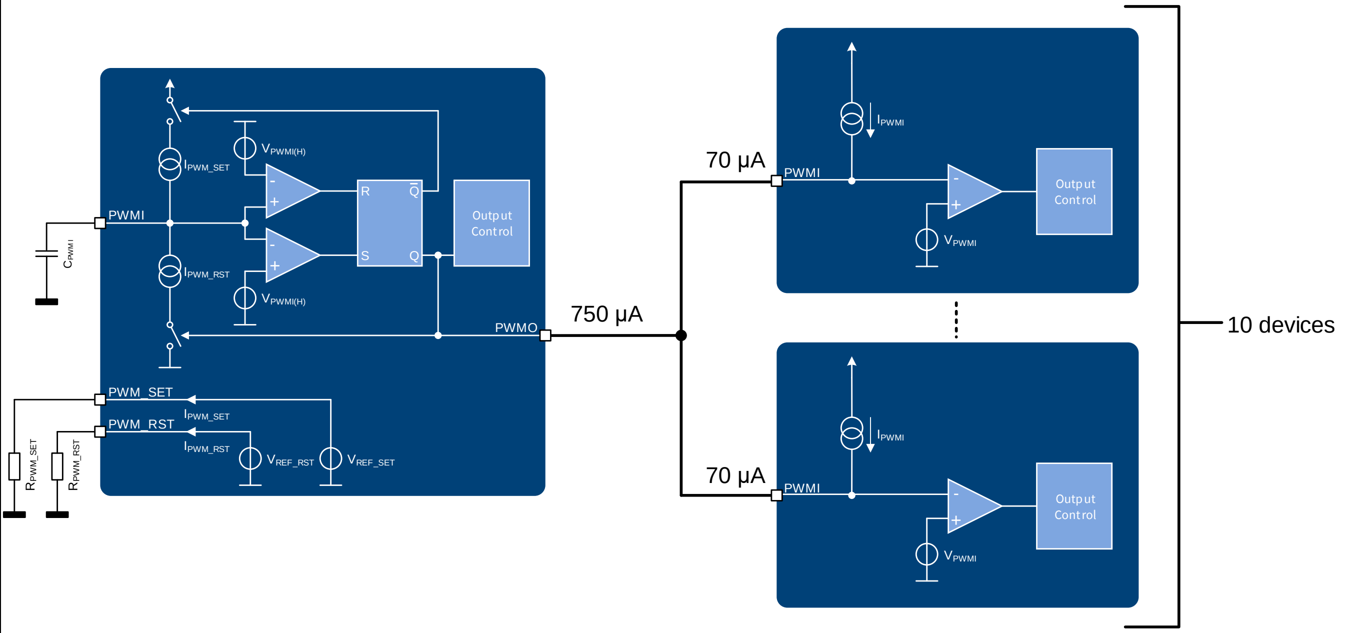

Figure 9 PWMO – PWMI connection with maximum allowed synchronized devices

Depending on the capacitive load on the PWMO pin and the number of devices connected together, a delay between the PWM signal of the master IC (TLD2142-1EP, TLD2141-3EP, TLD2252-2EP) and one of the slaves (TLD1114-1EP, TLD2132-1EP, TLD2131-3EP, TLD2331-3EP) may be introduced. This delay on the switch-on time of the slave devices needs also to be considered and depending the application conditions the maximum number of connected devices could be reduced.

In an application where more than 10 devices are needed, an additional high end device can be used to increase the total number of synchronized devices. This can be done by connecting the PWMO line of the first high end device into the PWMI pin of the second device. When the PWM_SET and PWM_RST pins of the second device are left open the PWMO pin of the second high end device mirrors the input signal (Figure 10).

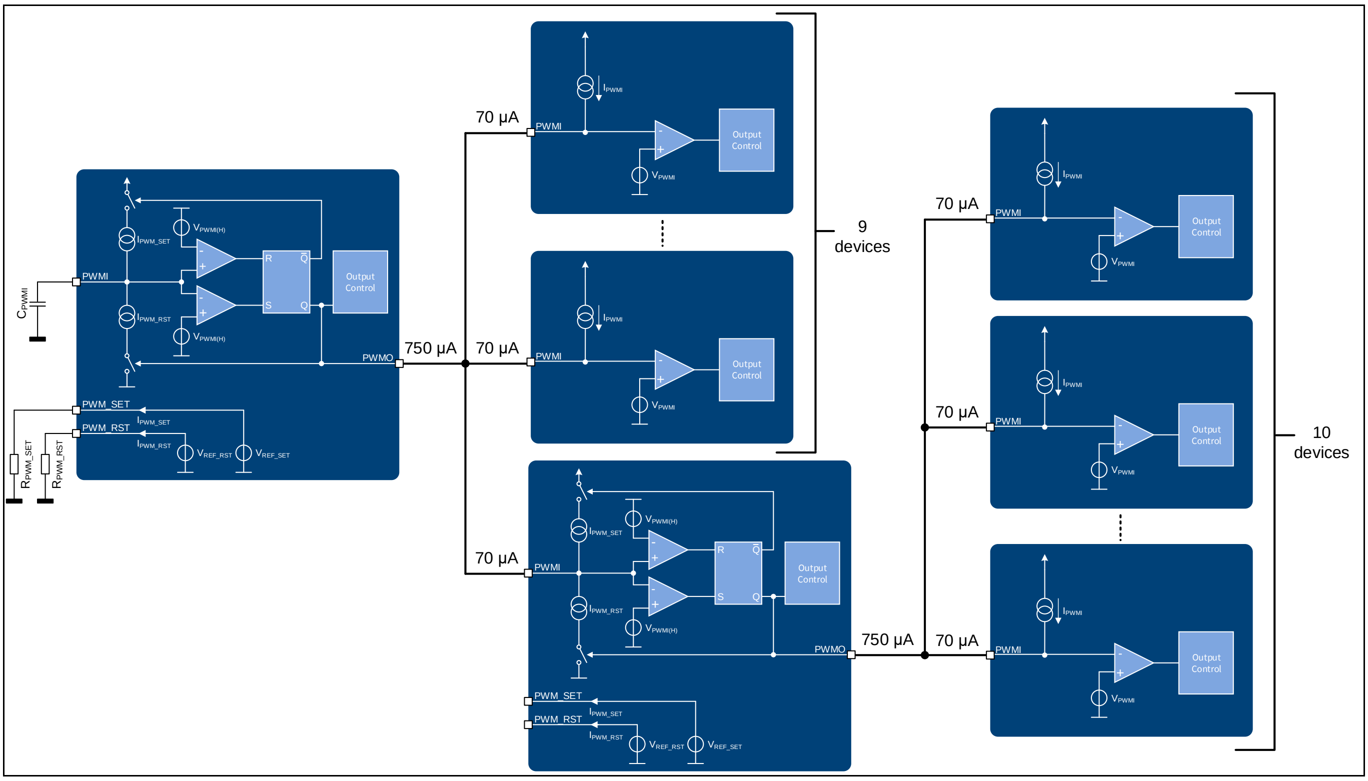

Figure 10 PWMO – PWMI connection with extended number of allowed synchronized devices

In an application where one Basic+ high end device (or a push-pull output of a microcontroller) drives several Basic+ high end devices via PWMO, the reference currents I_{PWM_SET} and I_{PWM_RST} can be set to 30 µA by placing two resistors at the respective pins. In this way the number of devices connected to the driver can be increased.

3 Application examples

An RCL application can be implemented in different ways depending on the OEM requirements. LITIX™ Basic+ high end group variants provide the required flexibility for the implementation of different RCL designs. In this chapter two RCL application examples will be shown using different LITIX™ Basic+ high end variants.

3.1 Application example with LITIX™ Basic+ TLD2141-3EP

The application conditions considered for this RCL application are the following:

- V_S = 8 V to 16 V
- 18 LEDs used for both Tail and Stop functions
- Output current for the Tail function I_{OUT} = 6 mA
- Output current for the Stop function I_{OUT} = 60 mA

Two LITIX™ Basic+ TLD2141-3EP will be used to implement both functions, with 3 LEDs on each channel. The integrated PWM engine for the first device will be used in order to achieve the two required levels of current. A typical 200 Hz PWM frequency is considered with 10% duty cycle. The PWMO pin of the first will be used to drive the second device.

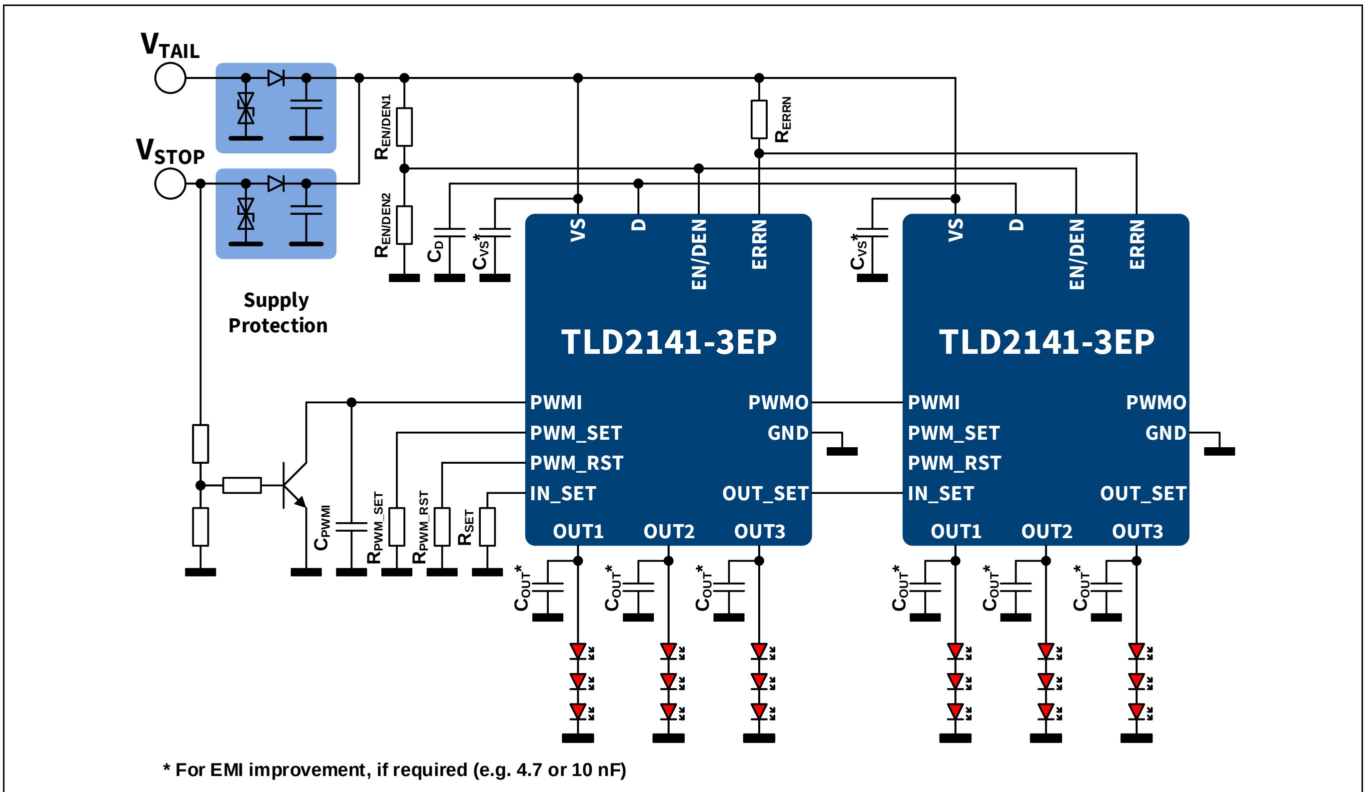

Figure 11 RCL application example with LITIX™ Basic+ TLD2141-3EP

As described in Chapter 2.1, the first step for the calculation of the PWM components is to define the highest current. Here, as the required duty cycle is less than 50%, the highest current is the I_{PWM_SET} current.

Thus, based on the limits in Table 1, I_{PWM_SET} = 270 µA.

The simplified formulas from Table 2 are used for the calculation of R_{PWM_SET} and R_{PWM_RST}:

$$R_{PWM\_SET} = \frac{V_{REF_{SET}/RST}}{I_{PWM_{SET}/RST}} = \frac{1.22\ V}{270\ \mu A} = 4.52\ k\Omega \tag{3.1.1}$$

$$R_{PWM\_RST} = R_{PWM\_SET} * \frac{1-D}{D} = 4.52\ k\Omega * \frac{1-0.1}{0,1} = 40.68\ k\Omega \tag{3.1.2}$$

Formula (2.1.3) is used to calculate the capacitor for PWMI pin:

$$f_{PWMI} = \frac{V_{REF_{SET/RST}}}{V_{PWMI(H)} - V_{PWMI(L)}} * \frac{1}{(R_{PWM\_SET} + R_{PWM\_RST}) * C_{PWMI}} \tag{3.1.3}$$

$$C_{PWMI} = \frac{V_{REF_{SET/RST}}}{\left(R_{PWM_{SET}} + R_{PWM_{RST}}\right) * f_{PWMI}} = \frac{1.22\ V}{(4.52\ k\Omega + 40.68\ k\Omega) * 200\ Hz} = 135\ nF \tag{3.1.4}$$

3.2 Application example LITIX™ Basic+ TLD2252-2EP

The application conditions considered for this RCL application are the following:

- V_S = 8 V to 16 V
- 6 LEDs, 3 for Tail and 6 for Stop function
- Output current for the Tail function I_{OUT} = 30 mA
- Output current for the Stop function I_{OUT} = 60 mA

One LITIX™ Basic+ TLD2252-2EP will be used to implement both functions, with 3 LEDs on each channel. A typical 200 Hz PWM requency is considered with 50% duty cycle.The integrated PWM engine will be used to drive OUT1 during Tail function while both OUT1 and OUT2 will be at full intensity during Stop function. The PWMO pin will be used to externally synchronize OUT1 to the PWMI pin state.

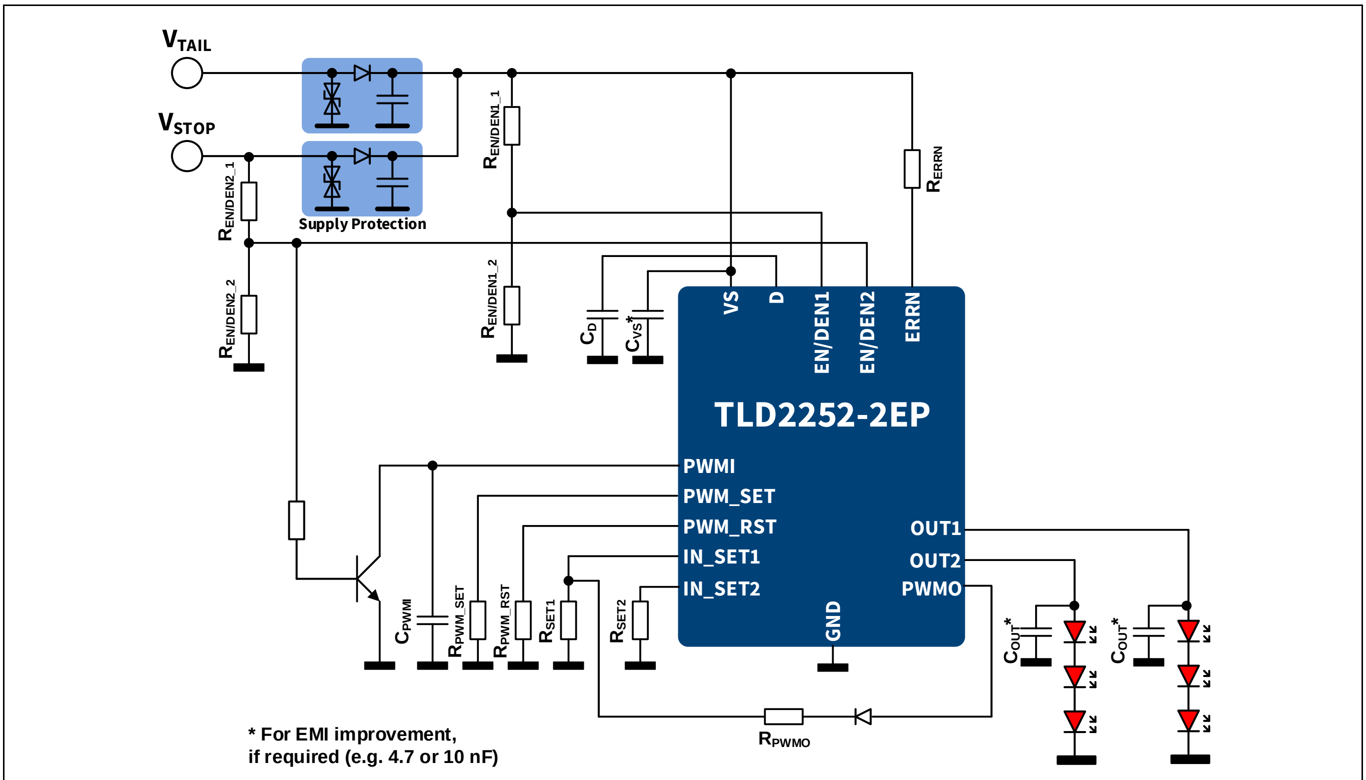

Figure 12 RCL application example with LITIX™ Basic+ TLD2252-2EP

As the PWM duty cycle is 50%, the I_{PWM_SET} and I_{PWM_RST} currents are equal (Table 2) and can be set anywhere within the optimized range (Table 1), depending the capacitance range which will be to use.

For the calculation, I_{PWM_SET} and I_{PWM_RST} are set to 50 µA. The simplified formulas from Table 2 are used for the calculation of R_{PWM_SET} and R_{PWM_RST}:

$$R_{PWM\_SET} = R_{PWM\_RST} = \frac{V_{REF_{SET/RST}}}{I_{PWM_{SET/RST}}} = \frac{1.22\ V}{50\ \mu A} = 24.4\ k\Omega \quad (3.2.1)$$

Formula (2.1.3) is used to calculate the capacitor for PWMI pin:

$$f_{PWMI} = \frac{V_{REF_{SET/RST}}}{V_{PWMI(H)} - V_{PWMI(L)}} * \frac{1}{(R_{PWM\_SET} + R_{PWM\_RST}) * C_{PWMI}} \quad (3.2.2)$$

$$C_{PWMI} = \frac{V_{REF_{SET/RST}}}{(R_{PWM\_SET} + R_{PWM\_RST}) * f_{PWMI}} = \frac{1.22\ V}{(24.4\ k\Omega + 24.4\ k\Omega) * 200\ Hz} = 125\ nF \quad (3.2.3)$$

Table 4 shows different possibilities depending on the capacitance range which will be used in the application.

Table 4 PWM component dimensioning possibilities based on PWMI capacitance range

I_{PWM_SET}, I_{PWM_RST}	R_{PWM_SET}, R_{PWM_RST}	C_{PWMI}
30 µA	40.6 kΩ	75 nF
150 µA	8.1 kΩ	376 nF
270 µA	4.5 kΩ	677 nF

Revision history

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