AN-1523 LP5521 Power Efficiency Considerations

ABSTRACT

LP5521 has several different means to improve power efficiency on application. With proper use, there can be significant power savings in standby and active operation mode. This application note describes how to use different LP5521 operation modes and how to write program sequences to get most of the power save mode.

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1 Operation Modes

Supply current for LP5521 operation modes are listed in Table 1.

Table 1. Supply Current for LP5521 Operation Modes

Symbol	Parameter	Condition	Typ	Units
I_{VDD}	Standby supply current	EN = 0 (pin), CHIP_EN = 0 (bit), external 32 kHz clock running or not running	0.2	µA
		EN = 1 (pin), CHIP_EN = 0 (bit), external 32 kHz clock not running	1.0	µA
		EN = 1 (pin), CHIP_EN = 0 (bit), external 32 kHz clock running	1.4	µA
	Normal mode supply current	Charge pump and LED drivers disabled	0.25	mA
		Charge pump in 1x mode, no load, LED drivers disabled	0.70	mA
		Charge pump in 1.5x mode, no load, LED drivers disabled	1.5	mA
		Charge pump in 1x mode, no load, LED drivers enabled	1.2	mA
	Powersave mode supply current	External 32 kHz clock running	10	µA
		Internal oscillator running	0.25	mA

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As seen from Table 1, the operation mode has a strong influence on the supply current. LP5521 changes its mode automatically to the least power consuming mode as possible, when the automatic charge pump mode (CP_MODE[1:0] = 11b) and the power save mode (PWRSAVE_EN = 1) control bits are set in the I^2C registers.

The STANDBY mode is entered if the address 00H register bit CHIP_EN or EN pin is low. This is the lowest power consumption mode. All circuit functions are disabled. If CHIP_EN bit is low and EN pin is high, the internal logic is powered, but the device is still disabled. External 32 kHz clock input buffers draw some current, which is why the current consumption is slightly higher when the clock is running. When CHIP_EN bit and EN pin are high, the device is in normal operation mode. The current consumption is presented block by block in the following chapters. Current consumption in power save mode is explained later in this document.

2 Charge Pump Control

The charge pump is controlled with two CP_MODE bits in register 08H. When bits are low, the charge pump is disabled and the output node is resistively pulled down. Note that it is still possible to drive one LED with the R driver, if the R_TO_BATT bit is enabled. This way it is possible to get power savings, when only one LED is driven.

Additionally, when the charge pump is disabled, it is possible to supply V_{OUT} externally. The charge pump reverse current blocking is always active, when V_{OUT} pin is high. Slew rate control should be used, when pulling V_{OUT} high externally. Reverse current blocking circuitry needs some time to wake up. When external voltage powers LEDs, there is no charge pump supply current. The charge pump mode must be "disabled" if external powering is used.

One LP5521 charge pump can supply V_{OUT} to two, three or even four LP5521s, if charge pump maximum current is not exceeded. Note that automatic gain change is not reliable, when one charge pump is used to power external devices. In some configurations also automatic gain change is possible, but this has to be determined case by case. Also note that automatic power save mode does not necessary work optimally, when many LP5521 are connected together and driven with one charge pump. When driving several LP5521 with one charge pump, the most optimal case is when all LP5521 are driving similar LEDs and have the same sequences. Then it is possible to get the most from the automatic gain change and power save mode. Configuration, where one LP5521 is supplying two V_{OUT}s is in Figure 1.

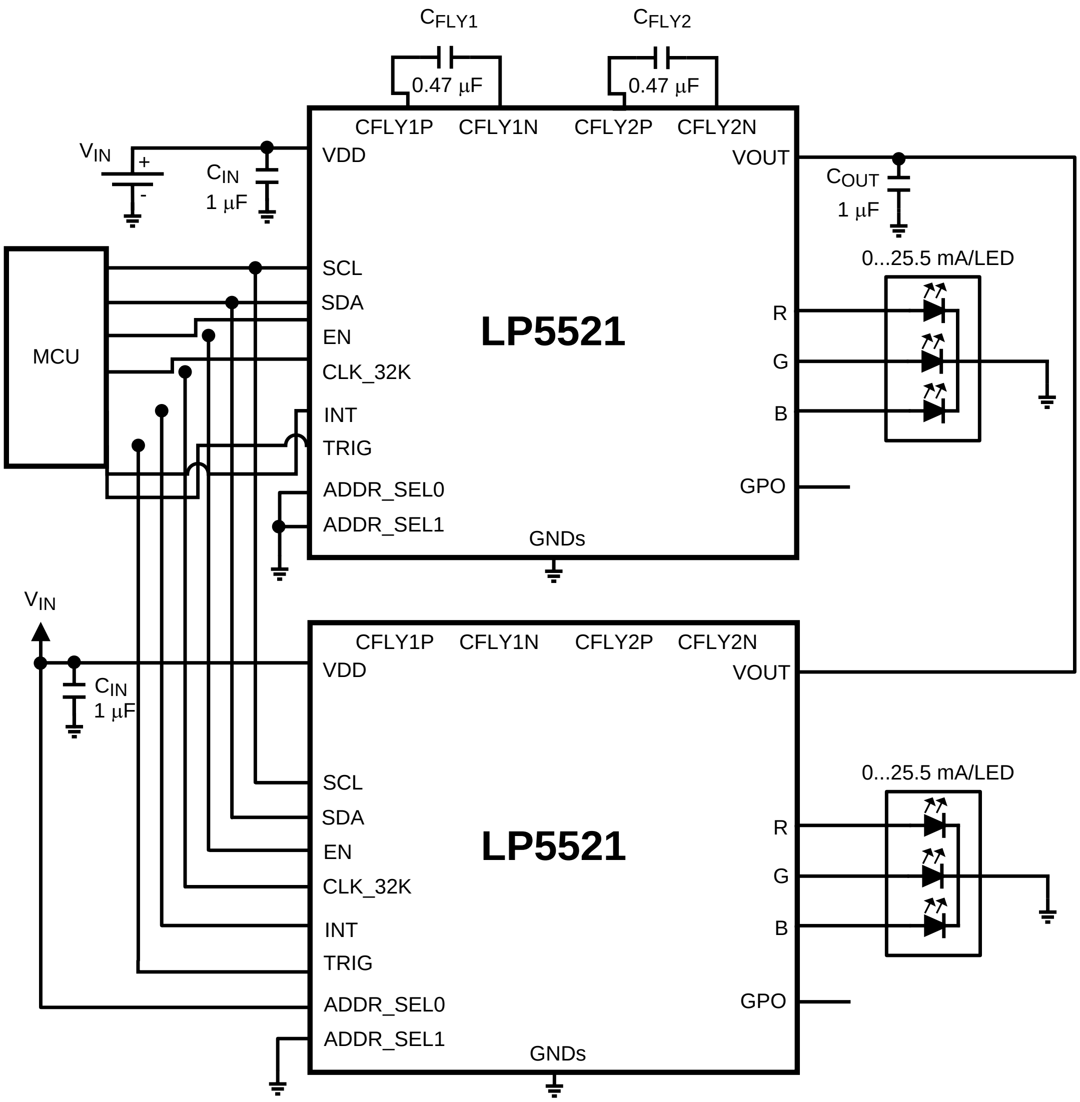

Figure 1. One LP5521 is Supplying Two V_{OUTs}

The charge pump can be forced to bypass mode, that is, the battery voltage is going directly to RGB drivers. In 1.5x mode output voltage is boosted to 4.5 V. In automatic mode, the charge pump operation mode is defined by the battery voltage level and the LED driver headroom. Operation modes and the selection bits are listed in Table 2.

Table 2. Operation Modes and the Selection Bits List

CONFIG Register (08H):		
Name	**Bit**	**Description**
CP_MODE	4:3	Charge pump operation mode 00b = Disabled 01b = Forced to bypass mode (1x) 10b = Forced to 1.5x mode 11b = Automatic mode selection

Typical current consumption measurement results of the charge pump in different operation modes are shown in Table 3. In automatic mode, current consumption is the same as in 1X or 1.5X mode.

Table 3. Typical Current Consumption Measurement Results of the Charge Pump in Different Operation Modes

Parameter	Condition	Typical	Unit
Charge pump supply current	Charge pump disabled, R_TO_BATT = 0/1	0	µA
	Charge pump active, 1x mode	470	µA
	Charge pump active, 1.5x mode	1220	µA

3 LED Driver Control

The R driver has two modes: current source can be connected to the battery (V_{DD}) or to the charge pump output. If current source is connected to the battery, the automatic charge pump gain control is not used for this output. This is to get better efficiency when the red LED with low V_F is connected to the R driver, and the battery voltage is high enough to drive this LED. The R driver mode can be selected with the I^2C register bit. When address is 08H, bit R_TO_BATT is 1, R current source is connected to battery. When it is 0 (default), R current source is connected to charge pump.

If all LED drivers are not needed, drivers can be enabled separately. The LED driver is disabled when address 01H R, G ,B_MODE register bits are 00b (default). Enabling drivers increase supply current. Typical current consumption measurement results of LED drivers are presented in Table 4. Note that the charge pump state effects the LED driver supply current. Input current is effectively multiplied by 1.5, when the charge pump is operating in 1.5x mode.

Programming output current with registers 05H-07H or pulse width modulation (PWM) value does not have significant effect on the LED driver internal current consumption.

Table 4. Typical Current Consumption Measurement Results of LED Drivers

Parameter	Condition	Typical	Unit
LED driver supply current	All drivers disabled	0	µA
	I_{LED}= 0 mA, 1 driver enabled, charge pump in 1x mode	310	µA
	I_{LED}= 0 mA, 2 drivers enabled, charge pump in 1x mode	375	µA
	I_{LED}= 0 mA, 3 drivers enabled, charge pump in 1x mode	440	µA
	I_{LED}= 0 mA, 1 driver enabled, charge pump in 1.5x mode	420	µA
	I_{LED}= 0 mA, 2 drivers enabled, charge pump in 1.5x mode	520	µA
	I_{LED}= 0 mA, 3 drivers enabled, charge pump in 1.5x mode	620	µA

4 System Level Partitioning

LP5521 users can save significant power by considering system level partitioning. This applies to the cases, where two or more LP5521s exist in the same system. The general rule is that LEDs with the most simultaneous activity are connected to one device. While one device is handling the frequent activity, the others can wake-up only when needed. While doing the partitioning, PWB routing and software issues should be considered also.

5 Automatic Power Save Functionality

Automatic power save mode is enabled when the PWRSAVE_EN bit in register address 08H is 1. Almost all analog blocks (including internal oscillator) are powered down in power save, if external clock is used. Only charge pump protection circuits remain active. However, if the internal clock has been selected, only the charge pump and the LED drivers are disabled during power save. The effect of internal vs. external clock can be seen on the power save current consumption figures. The sequence engine remains active during power save mode. In both cases, the charge pump enters to 'weak 1x' mode. In this mode, the charge pump utilizes a passive current limited keep-alive switch, which keeps the output voltage at battery level. When several LP5521 are driven with one charge pump, this must be considered to prevent shutting down the charge pump, when some of the chips need the charge pump voltage to drive LEDs.

During program execution, LP5521 can enter power save if there is no PWM activity in R, G and B outputs. To prevent short power save sequences during program execution, LP5521 has command look-ahead filter. In every instruction cycle R, G, B commands are analyzed, if there is sufficient time left with no PWM activity the device will enter power save. In power save program execution continues uninterruptedly. When a command that requires PWM activity is executed, fast internal start-up sequence will be started automatically. Table 5 describes commands and conditions that can activate power save. All channels (R,G,B) need to meet power save condition in order to enable power save.

Table 5. Commands and Conditions That Activate Power Save

Led Controller Operation Mode (R,G,B_MODE)	Power Save Condition
00b	Disabled mode enables power save
01b	Load program to SRAM prevents power save
10b	Run program mode enables power save if there is no PWM activity and command look ahead filter condition is met
11b	Direct control mode enables power save if there is no PWM activity
Command	**Power Save Condition**
Wait	No PWM activity and current command wait time longer than 50 ms. If prescale = 1 then wait time needs to be longer than 80 ms (see Figure 2 and Figure 5).
Ramp	Ramp command PWM value reaches minimum 0 and current command execution time left more than 50 ms. If prescale = 1 then time left needs to be more than 80 ms (see Figure 3).
Trigger	No PWM activity during wait for trigger command execution (see Figure 4).
End	No PWM activity or Reset bit = 1 (see Figure 4).
Set PWM	Enables power save if PWM set to 0 and next command generates at least 50 ms wait
Other commands	No effect to power save

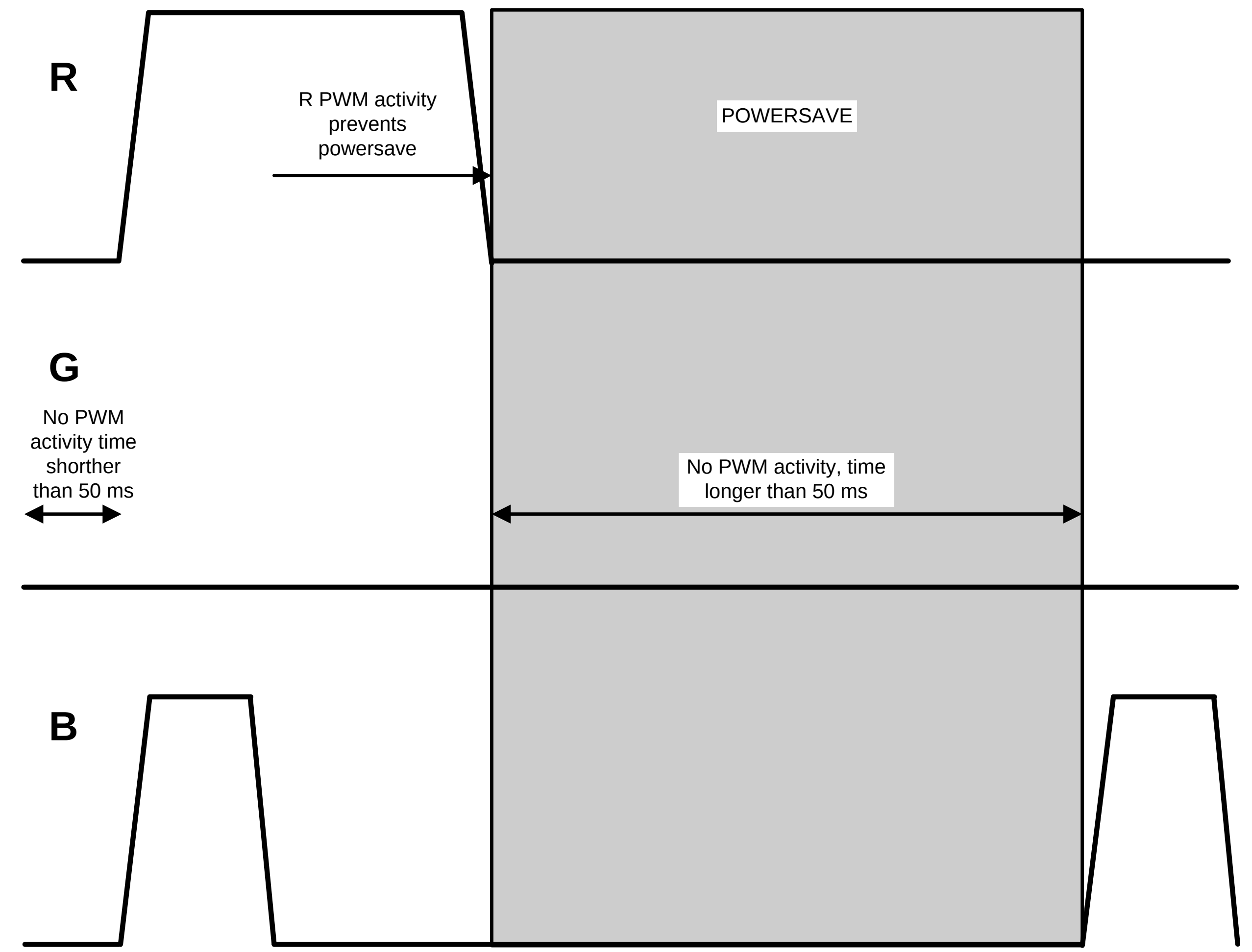

Figure 2. Basic Power Save Sequence With Long Inactive Period

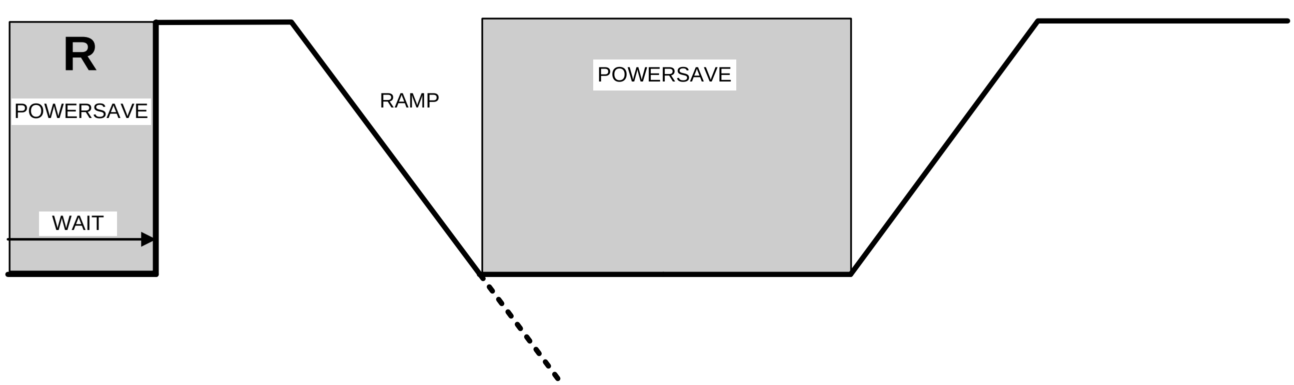

Figure 3. Power Save Sequence With a Ramp Command Used as Combined Ramp/Wait

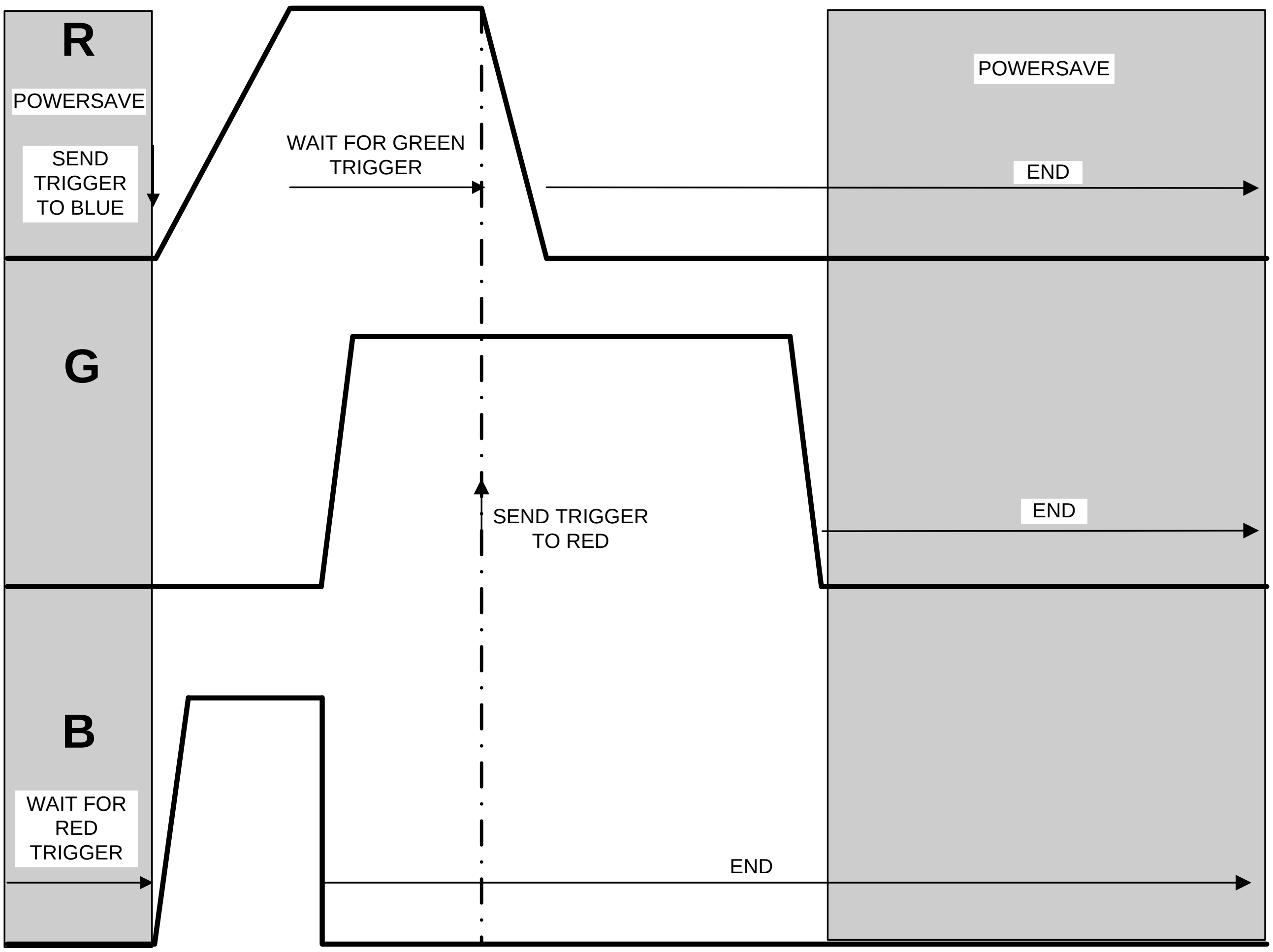

Figure 4. Power Save Sequence With Wait for Trigger Command

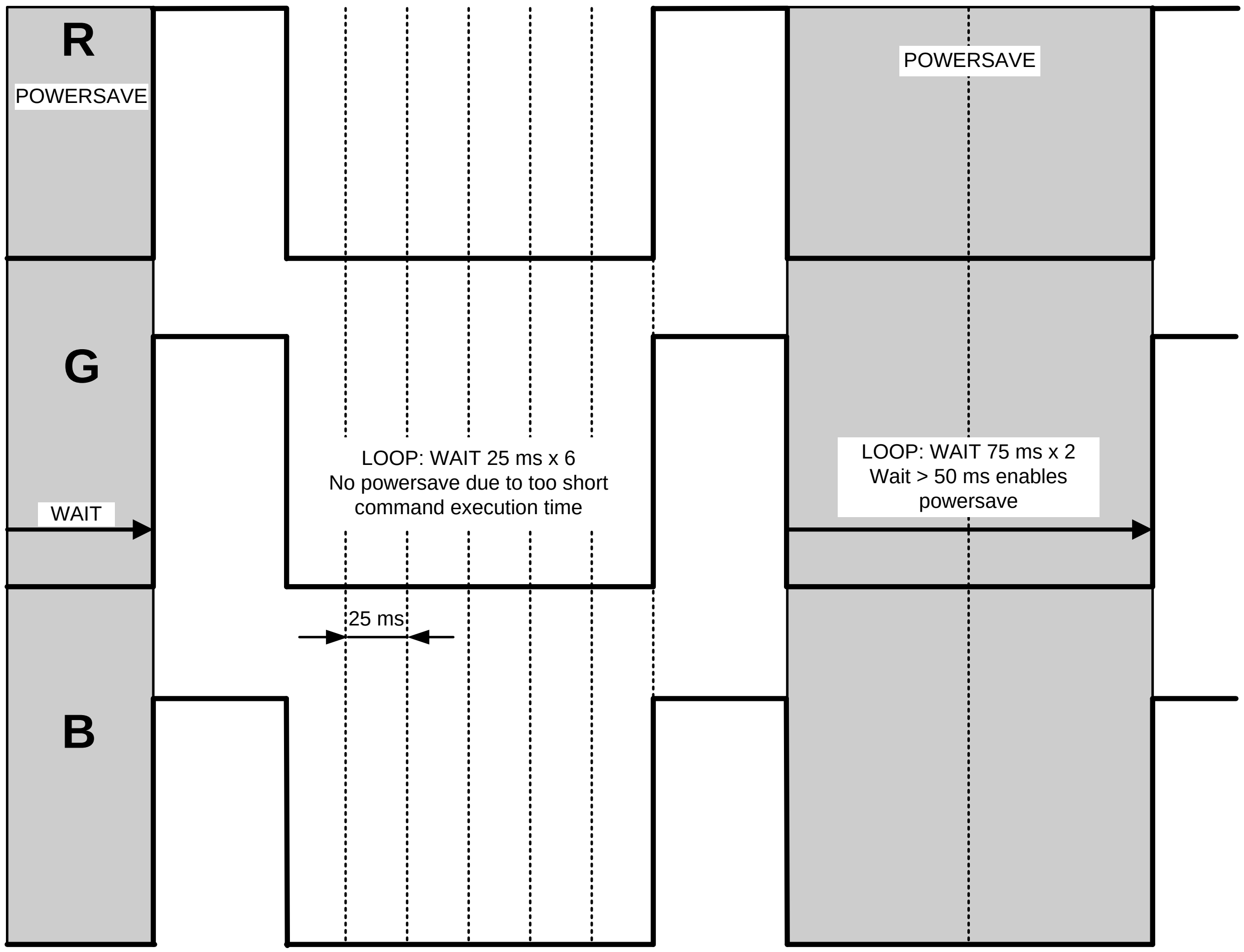

Figure 5. Power Save Sequence With Long and Short Wait Commands

6 Automatic Power Save Efficiency

Effectiveness of power save mode strongly depends on the program code. If the LEDs are constantly active, the power save mode is not activated at all. Programs with low "duty cycle" gain most of the power save mode.

Table 6 shows that power save drops supply current below 1% of active operation current consumption, when only the charge pump is enabled and no LED activity.

Table 6. Effectiveness of Power Save Mode

Charge Pump Mode	Supply Current Power Save Disabled (mA)	Supply Current Power Save Active (mA)	Supply Current Reduction (%)
Charge pump 1x mode	1.18	0.01	99.15
Charge pump 1.5x mode	2.09	0.01	99.52

To demonstrate power save effectiveness during program execution below is presented in a couple of programs.

A typical phone indicator light could for example be 20 ms blink every 4s, 2s or 1s. This example device uses an external clock. The PWM duty cycle is set to 100% and the LED current is 5 mA. The R_TO_BATT driver has been used in cases when the charge pump has been disabled.

One column in the table shows average battery current without LED current. LED current has been subtracted from the results by calculating average LED current for the whole period by following equation: $I_{LEDAVG} = (T_{ACTIVE} / T_{PERIOD}) \times I_{LED}$. Subtracted LED currents for 4s, 2s and 1s periods are 25 µA, 50 µA, 100 µA, respectively. In 1.5X mode, the LED currents get multiplied. Input current is roughly 1.5 times the LED current. This has been taken into account in Table 7.

Table 7. Powersave Effectiveness During Program Execution

Blinking Cycle	Charge Pump	Current With Power Save (µA)		Avgerage Current No Power Save (µA)	Saved Power (%)
		Average	Average Without LED		
4.12s	OFF	40	15	620	93.5
4.12s	1x	40	15	1170	96.5
4.12s	1.5x	50	15	2070	97.5
2.07s	OFF	60	10	640	90.5
2.07s	1x	70	20	1190	94.0
2.07s	1.5x	100	25	2100	95.0
1.05s	OFF	110	10	670	83.5
1.05s	1x	140	40	1230	88.5
1.05s	1.5x	200	50	2160	91.0