SAMSUNG
ELECTRONICS

APPLICATION NOTE

S3F84A5

An LED Lighting System

January 2010

Revision 0.00

Important Notice

S3F84A5 An LED Lighting System
Application Note, Revision 0.00

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1 OVERVIEW OF HPLED LIGHTING CONTROL SYSTEM

A light-emitting diode (LED) is a semiconductor light source that presents several advantages over traditional light (like incandescent) sources such as lower energy consumption, longer lifetime, improved robustness, smaller size, faster switching, and greater durability and reliance. It renders “green” light and does not contribute towards material pollution or radiations. Usually, an LED can also be referred to as HPLED (high power LED) if the NRP (normal rated power) is greater than 1W. It can be driven at currents that vary from hundreds of mA to more than an ampere. LEDs can produce hundreds of lumens, and find extensive usage in lighting systems.

This document presents a simple HPLED lighting control system implemented with Samsung’s 8-bit MCU S3F84P4.

1.1 PIN ASSIGNMENT IN S3F84P4

Figure 1-1 shows the pin assignment in S3F84P4.

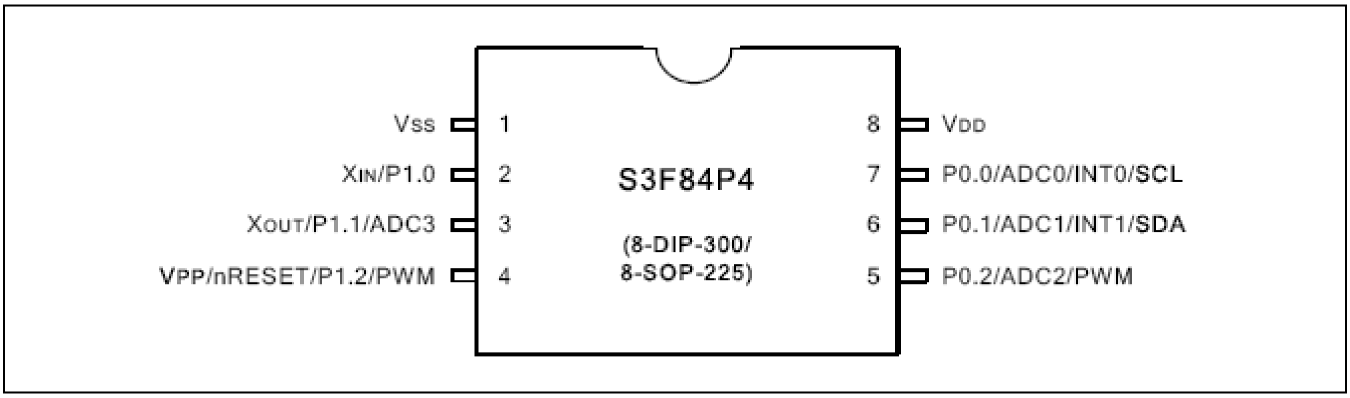

Figure 1-1 S3F84P4 Pin Assignment

1.2 KEY FEATURES OF S3F84P4

The key features in S3F84P4 include:

- 4 kbyte Flash ROM or 208 Byte SRAM
- 6+6 PWM x 1
- 10-bit ADC x 4
- 8-bit Basic Timer (can be used as watchdog timer)
- 16-bit Timer0 (can be used as Timer A or B, the two 8-bit Timers)
- EXINT X 2
- Supports Configurable LVR (2.2/ 3.0/ 3.9V)
- Supports Configurable RC (1M/ 8MHz @5V)
- Supports six IOs (maximum) when using internal LVR and internal RC

1.3 SYSTEM PRINCIPLE

The two considerations for HPLED are:

1. Forward voltage
2. Constant control current

Different LED applications have different characteristics. For instance, LEDs come in different colors. In some cases, manufacturers of the LED applications might also differ. Even if the LED applications come from the same manufacturer, it can lead to differences in forward voltage. In such cases, constant voltage power cannot work.

Different LED applications should select different power suppliers according to its characteristics. For instance, by considering efficiency, switch module power supplier (SMPS) can be chosen for different LED applications. SMPS consists of Buck, Boost, or Buck-Boost circuits.

The duty cycle of Buck circuit is $D = \frac{V_O}{V_I}$. It is only used when the power supply is higher than the forward voltage, that is, $V_O < V_I$.

The duty cycle of Boost circuit is $D = \frac{V_O - V_I}{V_O}$. It is only used when the forward voltage is higher than the power supply, that is, $V_O > V_I$.

The duty cycle of Buck-Boost circuit is $D = \frac{V_O}{V_O + V_I}$. It can be used without considering the relationship of power supply and forward voltage.

In this application, buck circuit is chosen to power a HKP-D1W1 white LED (forward voltage 3.5V) with a DC power source of 5V.

1.3.1 BUCK CIRCUIT

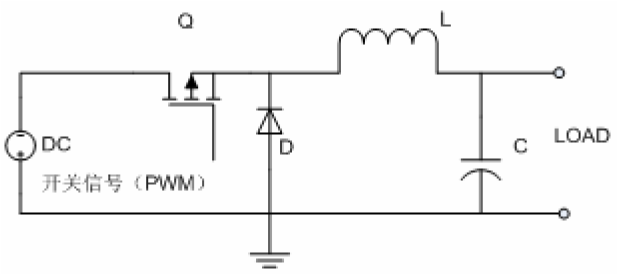

Figure 1-2 Simplified Buck Circuit

Buck circuit works when a switch signal turns on the transistor (Q). The DC power then starts to charge the coil (L). When the current reaches a predefined level, change the transistor state from On to Off using the switch signal. At this time, since the coil will have inertia to keep the current direction, the load still can be powered with a freewheeling diode until the switch signal turns on the transistor again. The resulting current is continuous but alternating (see *Figure 1-3* for more details).

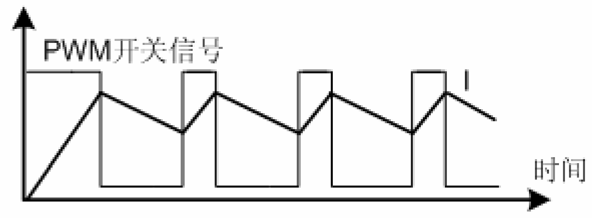

Figure 1-3 Current on load

1.3.2 SUMMARY

- The average current over load is determined by the duty cycle of switch signal.
- SMPS can lead to current ripple. But it could be alleviated by increasing the PWM frequency or coil inductance value, or by adding extra filtering circuits.

1.3.3 CONSTANT CURRENT CONTROL

Refer to the HKP-D1W1 datasheet to see the relationship of forward voltage, forward current, and relative luminous flux.

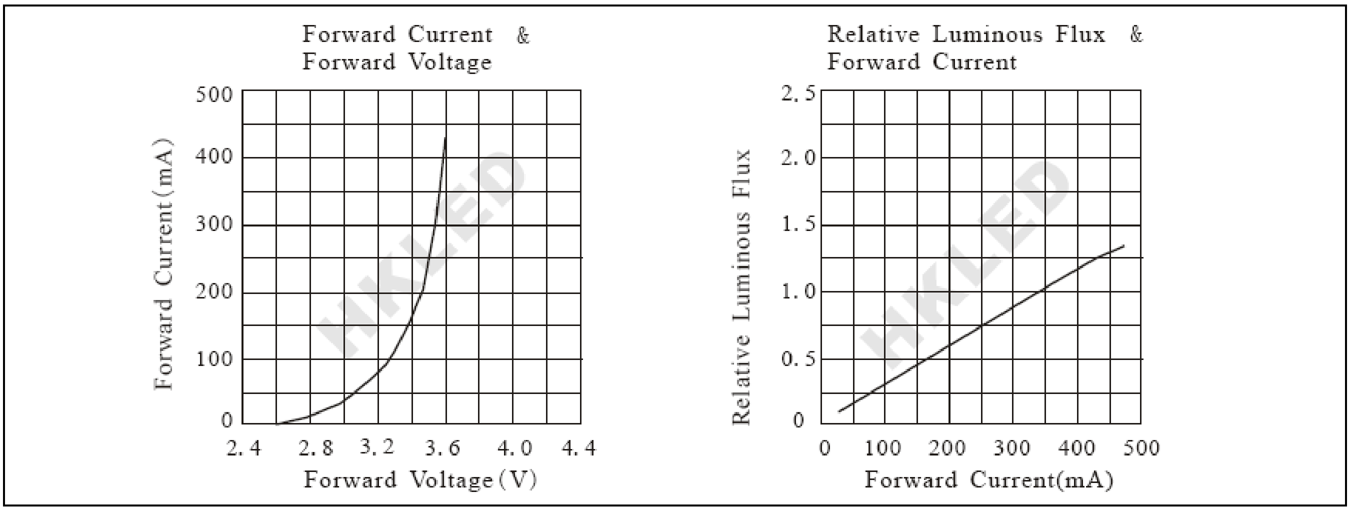

Figure 1-4 HKP-D1W1 Forward Voltage, Forward Current, and Relative Luminous Flux

As shown in *Figure 1-4*, describing the luminous flux as a function of current is better than describing it as a function of voltage. Even a slight change of voltage might lead to significant current shift. Therefore, constant current control is used in HPLED applications.

2 HARDWARE IMPLEMENTATION

2.1 SYSTEM DIAGRAM AND CIRCUIT

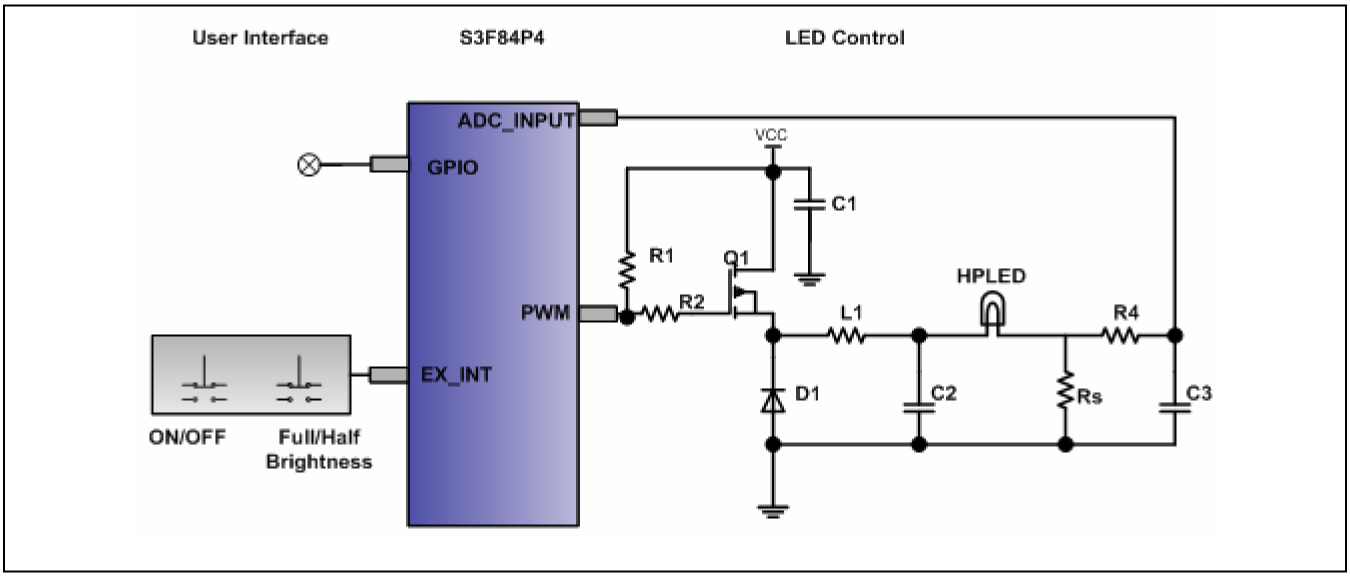

Figure 2-1 Control Circuit

As shown in *Figure 2-1*, the Buck Circuit comprise of Q1, L1, D1, and C2. The output of PWM turns on/off the transistor (Q1). The current over HPLED is sensed by a 1ohm power resistor. It then goes into S3F84P4's ADC module after passing through a filter composed of R4 and C3.

Brightness can be obtained by changing the PWM duty cycle after comparing the actual sensing value and target forward current. This application uses two external interrupts ("ENINT" and "GPIO" as shown in *Figure 2-1*) as keys to control the turn-on/off and brightness. A normal LED indicates the current brightness as full or half brightness.

2.2 COMPONENTS SELECTION

Assume the following two conditions:

$$V_O = (V_{FW} + I_{FW} \times 1ohm) = 3.5 + 0.35 = 3.85V$$
$$V_I = 5V$$

If non-divided system clock is selected as the clock source of the 6+6 PWM, its base frequency is $\frac{f_{OSC}}{2^6} = 125KHz$.

2.2.1 SELECT THE INDUCTANCE (L1) FOR THE REQUIREMENT OF CURRENT RIPPLE

$$L_1 = \frac{V}{\frac{\Delta I}{\Delta T}} = \frac{(V_I - V_O) \times \frac{D}{f_{PWM}}}{I_{ripple}}$$
$$L_1 \times I_{ripple} = (5 - 3.85) \times \frac{3.85}{5 \times 125K} = 7.084\mu$$

Therefore, 20% current ripple means $L_1 > 100uH$.

2.2.2 SELECT THE CAPACITANCE (C2) FOR THE REQUIREMENT OF VOLTAGE RIPPLE

To reduce the voltage ripple and power loss, a capacitor with small ESR like Tantalum Capacitor should be chosen as C2. When ESL and ESR are negligible, then,

$$C_2 = \frac{\frac{\Delta I}{f_{PWM}}}{V_{ripple}}$$
$$C_2 \times V_{ripple} = \frac{0.35 * 0.2}{125K} = 0.56\mu$$

Therefore, 1% voltage ripple means $C_2 > 47uF$.

The freewheeling diode should be a Schottky diode, as the system requires low turn-on voltage and fast switching.

3 SOFTWARE IMPLEMENTATION

Figure 3-1 shows the software implementation.

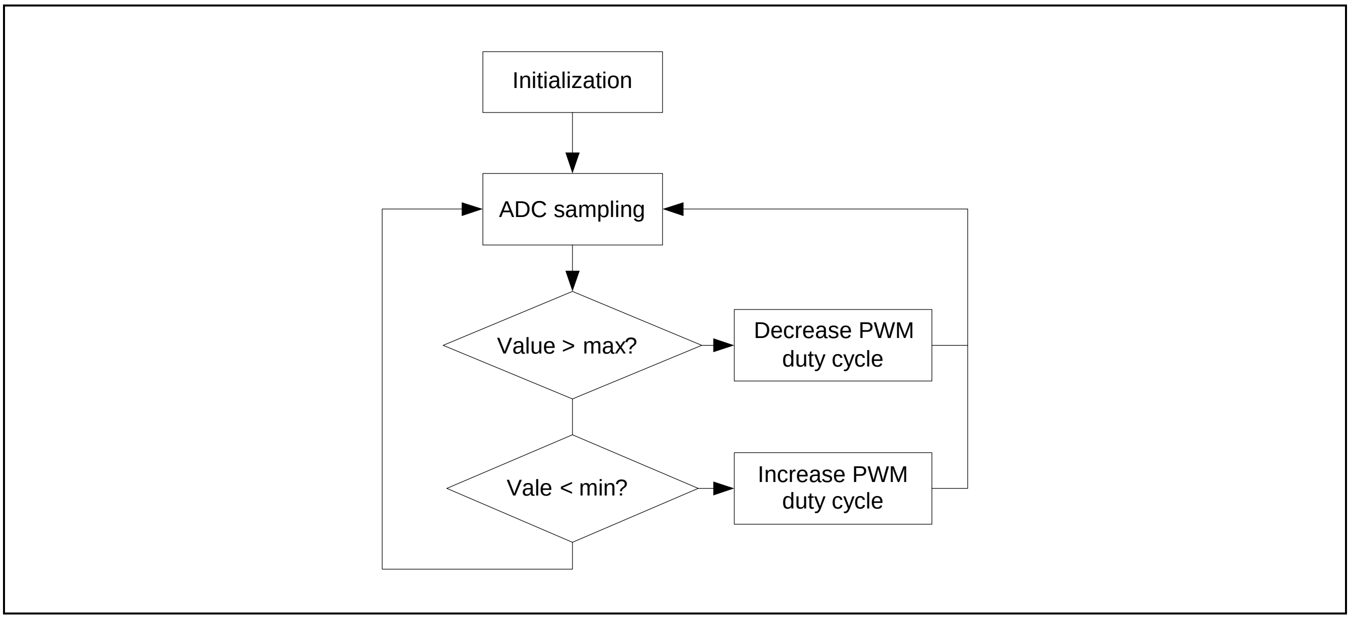

Figure 3-1 Software Implementation Diagram

Since the PWM in S3F84P4 is 6+6 type, it affects the software in two ways.

- Way to change the PWM duty cycle: The duty cycle is the result of both the register values of PWMDATA and PWMEX. Therefore, any increase or decrease in register from PWMDATA will not change the duty cycle. For more details on register PWMEX, refer to the S3F84P4 User's Manual. Figure 3-2 shows the right way to change the PWM duty cycle.

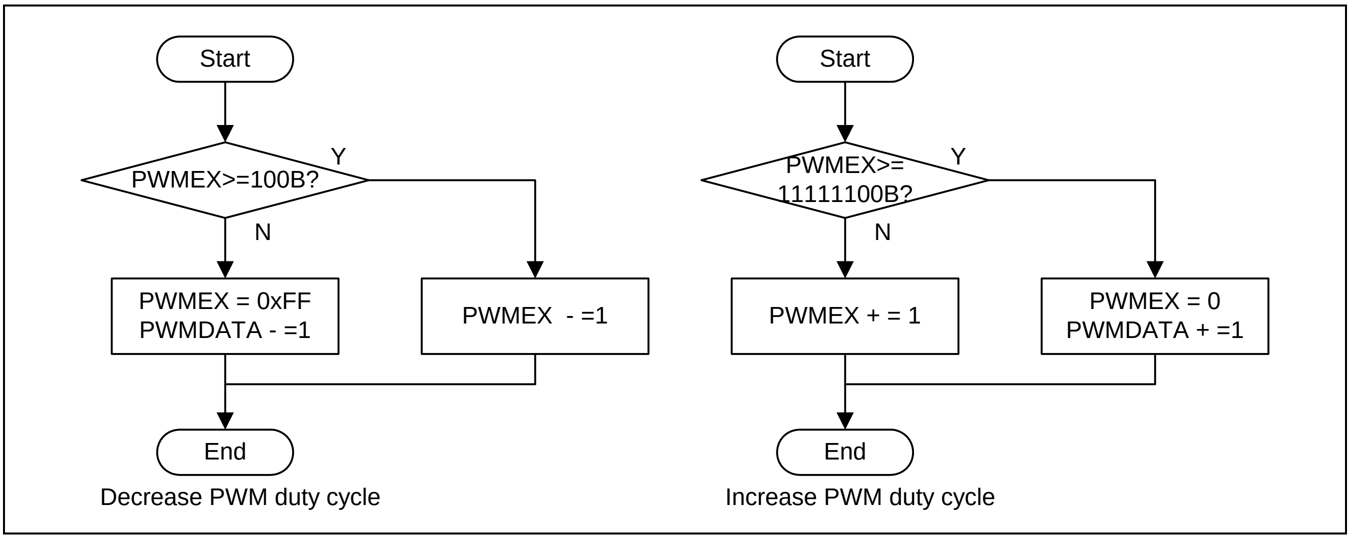

Figure 3-2 Way to change PWM duty cycle

- Change rate of PWM duty cycle: If PWM in S3F84P4 is 6+6 type, the PWM basic frequency is 6-bit, that is, $\frac{f_{PWM}}{2^6} = \frac{8MHz}{64} = 125KHz$ when $f_{PWM} = 8MHz$. The overall cycle is still 12-bit to make the 12-bit resolution fully valid, that is, $\frac{2^{12}}{f_{PWM}} = \frac{4096}{8MHz} = 0.512ms$. So Therefore, every change of the duty cycle will take effect after 0.512ms. Considering the AD conversion duration is 25us, duty cycle can be updated every 21 times of AD conversion.

4 SYSTEM VALIDATION

Figure 4-1 shows the current ripple and voltage ripple test waveform. Red and blue colors specify the current and voltage, respectively.

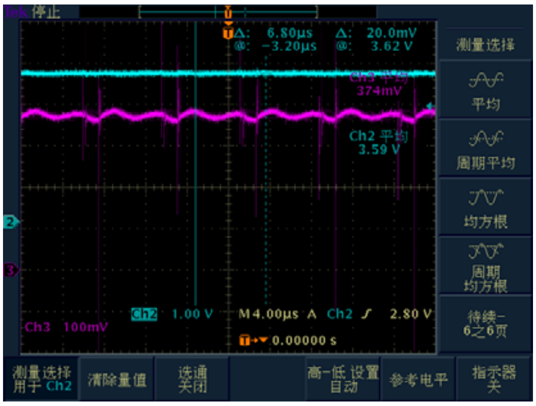

Figure 4-1 Waveform for HPLED forward voltage and current

$$efficiency = \frac{(V_{fd} - V_s) \times \frac{V_s}{R_s}}{(I_{ps} - I_{MCU}) \times V_{ps}}$$ and $$V_{ps} = 5V$$

Based on the above formulas, Table 1 shows the values of Ips, Imcu, Vfd, Vs, and efficiency (%).

Table 4-1 System validation of efficiency

	#1		#2		#3		#4		#5	
	BD1	**BD2**	**BD1**	**BD2**	**BD1**	**BD2**	**BD1**	**BD2**	**BD1**	**BD2**
Ips (power supply) (mA)	300	288	306	285	300	288	309	290	308	304
Imcu (mA) (MCU供电LED)	18	19	18	19	18	19	18	19	18	19
Vfd V）	3.82	3.6	3.85	3.60	3.86	3.6	3.90	3.59	3.90	3.65
Vs mV）	357	340	359	340	351	340	359	341	358	360
Efficiency（%）	87.68	81.6	87.03	82.5	87.35	81.6	87.37	80.95	87.45	81.11

NOTE: BD1 and BD2 represent two boards, where the basic difference lies in the value of sensing resistance, $R_S(BD1) = 1.0\Omega$; $R_S(BD2) = 1.1\Omega$. Due to the same reason, the efficiency of BD2 is always better than that of BD1. The nominal tolerance of VISHAY WSR2 is 1%.

5 APPENDIX

5.1 BOM LIST OF KEY CIRCUIT

Table 5-1 shows the BOM list of key circuit.

Table 5-1 BOM list of Key Circuit

Reference	Description	Manufacturer	Part number
R1	1K ohms		
R2	10 ohms		
Rs	Current sensing Resistor	VISHAY®	WSR21R000FEA
C1	104		
C2	47uF Tantalum Capacitor		
C3	2nF		
C4	100uF		
R4	33K ohms		
Q1	HEXFET Power MOSFET	IR®	IRF9540
D1	Schottky Diode		IN5819
L1	100 uH inductance	TDK®	VLF12060-101M1R0
HPLED	1W1 HPLED	HangKe®	

5.2 APPENDIX 2: SOURCE CODE

For more information, refer to Source_Code_LED_S3F84P4_V10.