Embedded Systems Hands-On 1: Design and Implementation of Hardware/Software Systems

Task 6: Analog Output

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In this task, two simple solutions for controlling analog output levels and high current flows with a microcontroller are analyzed. It is scheduled for one week.

Summary

- Generating and filtering PWM signals
- Controlling bipolar transistors

Digital GPIO pins of microcontrollers are only able to generate two different output voltages (i.e., the reference potential V_{SS}, and the supply voltage V_{DD}. The GPIO output drivers are typically realized as MOSFETs and are thus only able to deliver a few milliamperes output current. Therefore, digital microcontroller outputs must not be used to drive analog actuators or high loads, such as piezo modules or bright LEDs. Additional external circuits are thus required to control those actuators.

Corona-Update: No measurement equipment is required.

1 Filtered PWM Signals

Summary

- [Qucs] simulation of PWM signals and dimensioning of the corresponding low-pass filter.
- PWM generation with the Cortex-M0
- Realization of ramp signals by controlling the PWM duty cycle

A PWM signal is a square wave and its duty cycle describes the ratio between the high time and the period of the signal. The average (i.e., zero-frequency component) of the square wave can be captured with a low-pass filter and increases with the duty cycle. Depending on the cutoff frequency and edge-steepness of the low-pass filter, some remaining noise (ripple) can be observed at the filtered PWM signal.

Simulate a 1 kHz PWM signal with a 3 V amplitude using [Qucs]. Use an equation module to parameterize the duty cycle and the PWM frequency. Do not include a parameter sweep block to analyze multiple duty cycles at once, as this will complicate later measurements. Add a first order RC low-pass filter (with parameterized cutoff-frequency) and visualize the filtered and unfiltered PWM signal as well as the amplitude of the remaining ripple of the filtered signal in a data display.

Choose the largest possible cutoff-frequency and corresponding nominal values for the resistor and capacitor such that the amplitude of the remaining ripple just falls below $\frac{3\,\mathrm{V}}{2^8}$ for all duty cycles.

Most timers of the Cortex-M0 support the generation of PWM signals. Choose a suitable timer, timer output channel, and output pin to implement the following interface. If required, the [ChibiOS] HAL may be utilized.

pwm.h

```c
/**
 * Initialize the timer and GPIO registers to generate and output
 * a PWM signal with a duty cycle of 50 %.
 * @param frequency the PWM frequency in Hz
 */
void pwm_init(uint32_t frequency);

/**
 * Modify the duty cycle of the PWM signal.
 * @param dc the new duty cycle in Q0.16 fixedpoint format
 */
void pwm_setDutyCycle(uint16_t dc);
```

Use this interface to set the brightness of one of the LEDs on the extension board. Document the duty cycle and an estimated brightness level for three different settings.

Generate a pulsing light by applying a 1 Hz triangle wave $t \mapsto 1\,\mathrm{V} \cdot (1 + |1 - ((2 \cdot 1\,\mathrm{Hz} \cdot t) \bmod 2)|)$ (i.e., 1.5 V average, 1 V peak to peak amplitude) by dynamic adjustment of the duty cycle. Tune the parameters to achieve a good optical result.

Minimum Expected Documentation

- Executable [Qucs] simulation with prepared data display
- Cutoff frequency, resistance, and capacitance of the low-pass filter
- Documented source code for PWM control and DC / dynamic signal generation

2 Bipolar Junction Transistor

Summary

- Differences between MOSFET and BJT
- Simulate characteristics of LED and BJT with [Qucs]
- Control LED brightness by choosing proper series resistors

In contrast to BJTs, the MOSFETs used in digital circuits are not able to deliver high load currents. Name three other significant differences between MOSFETs and BJTs that have to be considered when selecting a transistor type for a certain application.

The behaviour of transistors and diodes is affected by various component properties. The [Qucs] simulation models thus have to be configured to match the behavior of specific components. Some already configured components are available in the [Qucs] library.

Simulate the set of characteristic curves of the [BC547B] NPN transistors as shown in Figure 1. Justify possible deviations between the simulated behaviour and the characteristics specified in the datasheet.

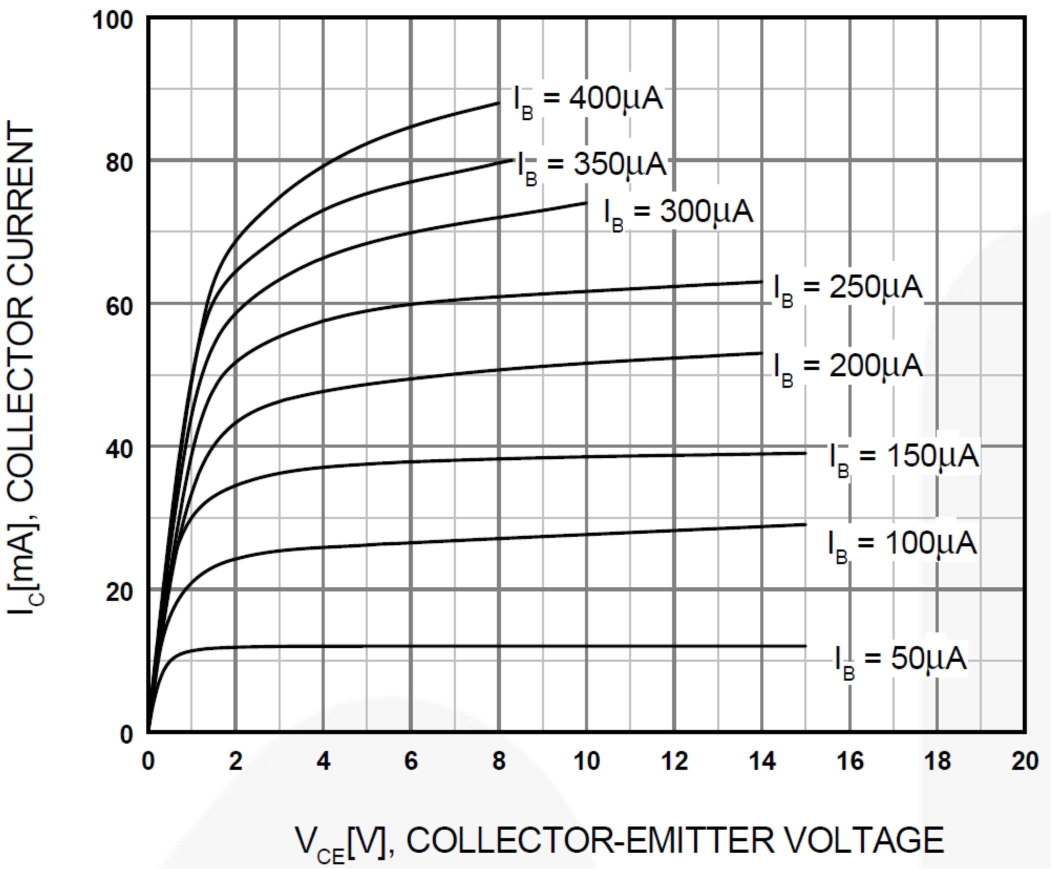

Figure 1: Characteristics of a [BC547B] NPN transistors

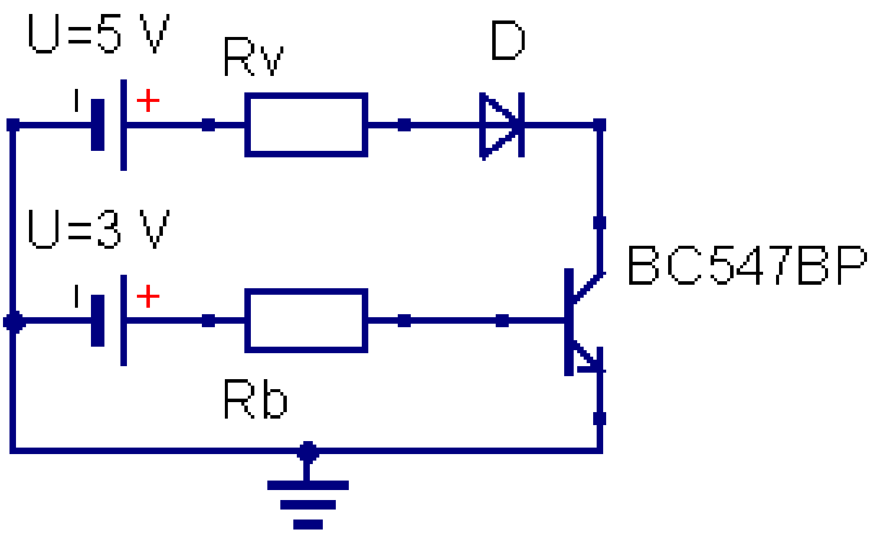

Figure 2: [Qucs] simulation of a [SLX-LX5093UWC] LED controlled by a [BC547B] NPN transistor

For components not available in the [Qucs] library, the parameters of a generic component model have to be adjusted to match the datasheet characteristics. Simulate the current-voltage curve of a [SLX-LX5093UWC] LED. See the `library/LEDs.lib` inside your [Qucs] installation for LED configuration examples.

Simulate the circuit shown in Figure 2 with [Qucs]. Choose the series resistor `Rv` such that the transistor is operated in active mode (i.e., collector current nearly independent from the collector-emitter voltage) when 25 mA are flowing through the LED. Simulate the dependency between the base resistor `Rb` and the diode current. Which base resistors are required to apply 15 mA, 20 mA and 25 mA to the LED? Which base current flows out of the 3 V source (e.g., a microcontroller GPIO pin) for these configurations?

Minimum Expected Documentation

- Selection criteria for MOSFET and BJT
- Executable [Qucs] simulation for
  - transistor characteristics (including reasons for deviations from datasheet)
  - diode characteristics
  - resistor-dependent diode and base current
- Determined base resistors and the corresponding base and diode current from simulation

Bibliography

BC547B Fairchild. *BC546 / BC547 / BC548 / BC549 / BC550 NPN Epitaxial Silicon Transistor*. URL: http://www.farnell.com/datasheets/1868820.pdf (visited on 2018-03-08).

ChibiOS *Free embedded RTOS*. URL: http://www.chibios.org (visited on 2018-03-08).

Qucs *Quite Universal Circuit Simulator*. 2015. URL: http://qucs.sourceforge.net/ (visited on 2018-03-08).

SLX-LX5093UWC Lumex. *Datasheet*. URL: http://www.farnell.com/datasheets/1503656.pdf (visited on 2018-03-08).

Acronyms

DC	Direct Current
GPIO	General Purpose IO
HAL	Hardware Abstraction Layer
LED	Light-emitting Diode
MOSFET	Metal-Oxid Semiconductor Field-Effect Transistor
PWM	Pulse-width Modulation
RTOS	Real-Time Operating System
$\mathbf{V_{DD}}$	Voltage Drain Drain. Electrical supply potential in MOSFET circuits
$\mathbf{V_{SS}}$	Voltage Source Source. Electrical reference potential in MOSFET circuits