Lab #8: Nested Timer Operations

Background

The term project develops a simple video game to be operated by a user with the D-pad. The video game will provide both audio and visual feedback to the user. The project is designed, tested, and evaluated over several weeks, and has the following parts:

1. D-Pad hardware (3 weeks ago)
2. LED display matrix (2 weeks ago)
3. PWM audio waveform generator (previous week)

This week, students design and test a program that combines all of the above parts to verify concurrent operation. Additionally, students will construct and test a speaker driver circuit to reduce the power consumption of the microcontroller itself.

Single Switch Speaker Drive Circuit

The single switch speaker drive circuit shown in Fig. 1 has been presented in the lab lecture; review the lecture slides to understand the various elements. Some design considerations are described next. This circuit, usually used to drive a motor, can also be used to drive a simple 8-Ω speaker; this is because directly connecting the speaker to the GPIO pins will attempt to sink more current than the GPIO pins can safely supply. Therefore, the 8-Ω speaker can be approximated the same as a simple DC motor.

A suitable transistor *Q* satisfies several ratings:

- In the ON state, the transistor must be able to conduct the full (maximum) load current. On a transistor datasheet, one should study the maximum rating for collector current I_C.
- In the OFF state, the transistor must withstand the full power supply voltage V_{CC}. On a transistor datasheet, one should study the maximum rating for collector-to-emitter voltage V_{CE}.

In the lab, either the 2N3904 or 2N2222 NPN small-signal transistors are provided, but students are also free to select other devices. Warning: if the transistor load is high (for example, supplying a continuous audio waveform for an extended period of time), then neither transistor can carry the increased current; one can expect smoke from the transistor! For normal operation, the maximum ratings of either transistor type are marginally acceptable. “Power transistors” having higher ratings are used in commercial practice.

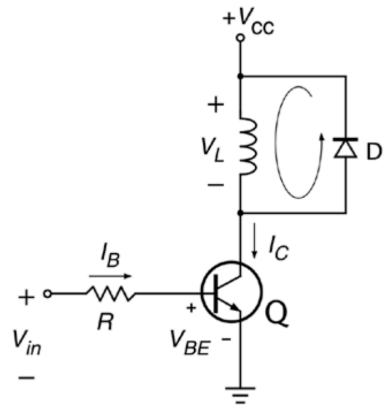

Figure 1: Speaker drive circuit using a single transistor; input V_{in} is from the microcontroller.

Diode *D* protects transistor *Q* during the “turn OFF” transient that occurs once every PWM cycle. A suitable diode *D* quickly switches state in response to the voltage transients associated with the inductive nature of the motor winding. In the lab, the 1N4148 or equivalent 1N914 switching diode is provided. These diodes are underrated for continuous full load current, but are marginally acceptable to conduct such current during the brief turn OFF transient time periods.

The resistor *R* must be designed this week. The resistor limits the base current I_B, so as to not exceed the microcontroller’s output current rating. On the other hand, an excessively large value of *R* prevents transistor *Q* from operating in the saturated state when turned ON. In the saturated state, the transistor’s collector-to-emitter voltage is called $V_{CE(sat)}$ and the value can be found in the transistor datasheet; typical values for a bipolar transistor are in the range of a few tenths of a volt. To design the resistance value, the following must be known:

- Maximum collector current expected by the load (call this I_{load})
- Bipolar transistor gain (*B* or h_{FE}) and base-to-emitter turn on voltage ($V_{BE(on)}$)
- Microcontroller output current characteristic for logic “high” (I_{IO})
- Microcontroller output voltage characteristic for logic “high” (V_{OH})

For the transistor to operate in a saturated state when ON, the base current I_B must be significantly larger than the ratio of the load current divided by the transistor gain, yet not exceed the microcontroller output current rating. That is:

$I_{IO} \geq I_B \gg \frac{I_{load}}{h_{FE}}$

The resistance value can then be calculated as:

$$R = \frac{V_{OH} - V_{BE(on)}}{I_B}$$

In modern power electronics, the MOSFET is very widely used for PWM applications. Design equations using a MOSFET for the saturation switch can be found in textbooks.

Digilent EEBoard Adjustable Power Supply

As illustrated in Figure 1, a power supply will supply the amplifier. The Digilent EEboard has adjustable positive and negative power supplies, labeled VP+ and VP-, respectively, on the power distribution block located at the bottom of the board. Output voltages are adjustable from 0 to ± 9 V_{DC}, with current limits adjustable from 0 to 1.5A. These values are selected in the *Waveforms Power Supplies and Voltmeters* instrument, as shown in Figure 2. Note that power must be turned on (in the upper left pane) and button "VP+ ON" must also be checked.

The VP+ output will be used to supply the speaker drive circuit (also labeled V_{CC} in Figure 1). The VP+ supply is to be configured for 9 V_{DC} with current limit 1.5 A. The ground connection of the VP+ supply is the ground connection in Figure 1. (The VP- supply is not used for this lab)

Important Note: The notation V_{CC} is widely used to denote power supplies, but this can create confusion when multiple power supplies are in a system. The notation is used two different ways in this lab, i.e. two different power supplies are both labeled V_{CC}. In *Waveforms*, the notation V_{CC} refers to the fixed supply (3.3 or 5 V_{DC}), which is not needed here, and can be turned OFF. But the same notation V_{CC} is used in Figure 1 to denote the power supply for the speaker drive circuit, which runs on 9 V_{DC}. BE VERY VCAREFUL to distinguish between the various uses of the symbol V_{CC}. The microcontroller board will be very unhappy if 9 V_{DC} appears on any of its pins!

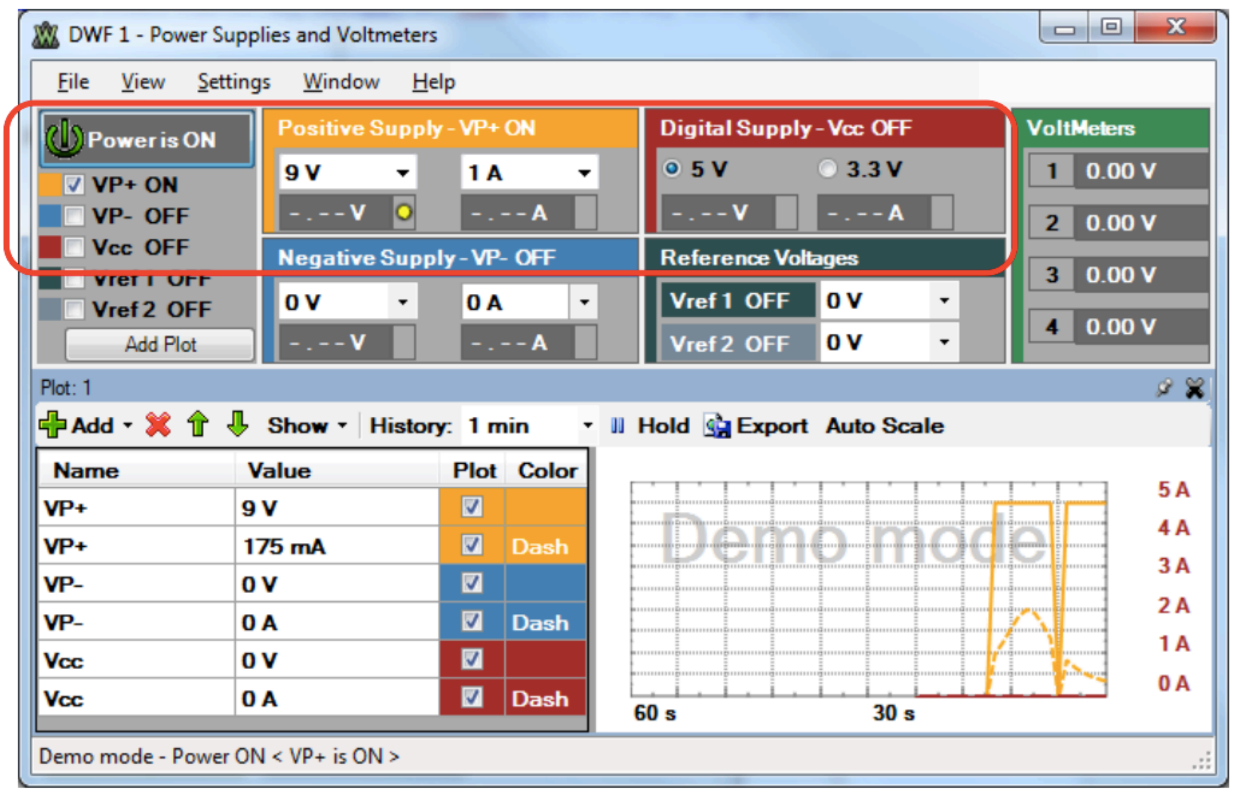

Figure 2: *Waveforms* window, showing positive power supply VP+ set on

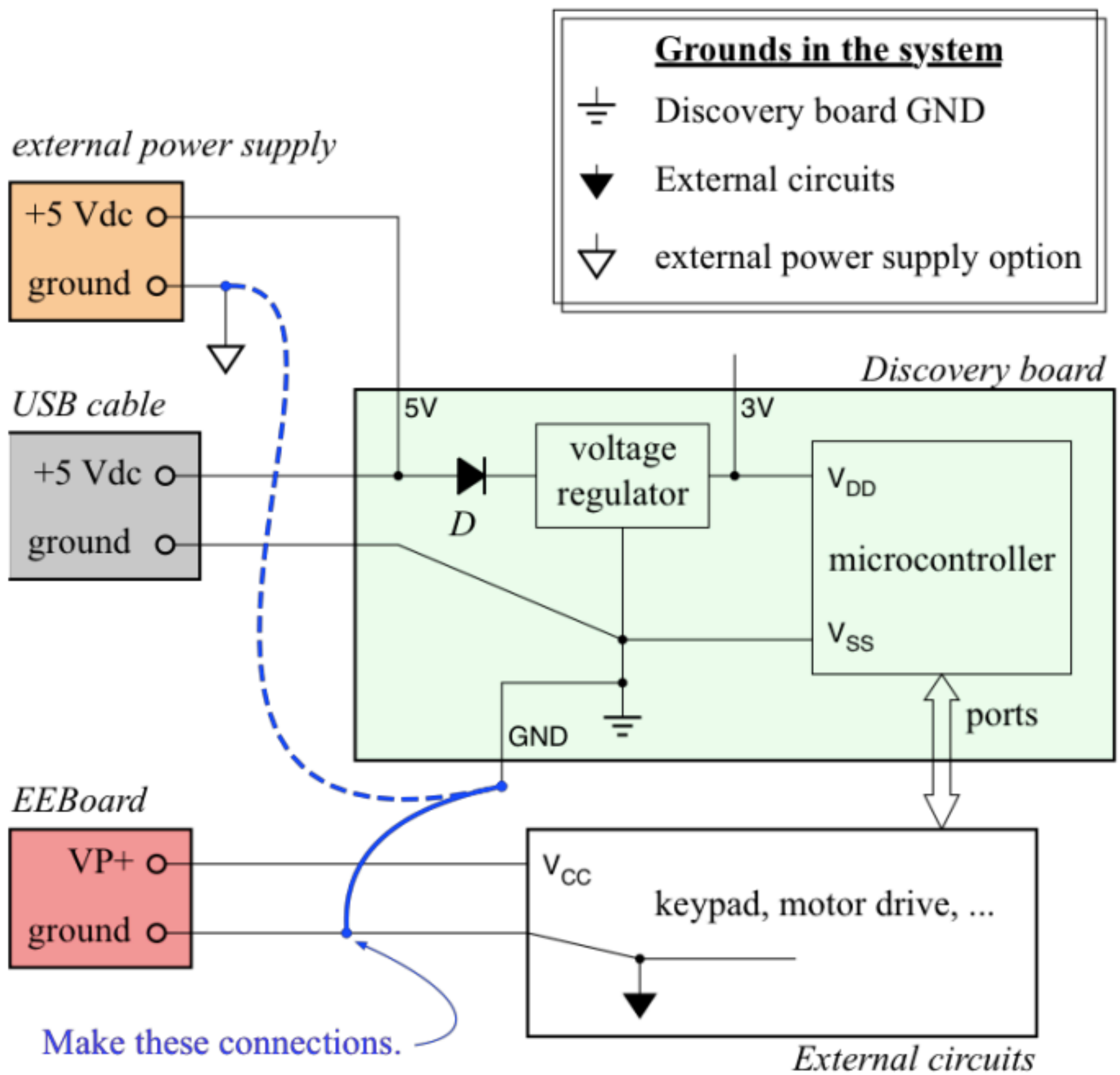

Figure 3: Grounds in the system should be connected in the laboratory, as shown in blue

Pre-Lab Asignment

Prior to lab, design a speaker drive circuit as described in the lab lecture. Use voltage and current characteristics for the 2N2222 BJT and 1N914 diode. These are the devices provided in lab, but students are free to choose other devices on their own. Study the ARM STM32L100RC pin (V_{OH}, I_{IO}: See Table 43 on page 74, Table 10 on page 43, and read the last sentence on page 73, “The GPIOs can…”). Then, design a value for the base resistor *R*.

In your laboratory notebook, write a test plan for testing the speaker drive circuit characteristics. Describe methods to measure the following operating characteristics:

1. V_{CE} – For the curious: measure with and without diode *D* in the circuit. Do not be surprised if transistor *Q* becomes damaged while *D* is removed.

2. $V_{CE(sat)}$ – to verify that transistor *Q* is saturated during ON periods of the PWM signal
3. $V_{BE(on)}$
4. V_{OH} – output of the microcontroller pin PA6, or speaker drive input voltage

The C program from the previous lab should be modified as necessary to produce the PWM audio signal to control the speaker. The duty cycle of the PWM signal should be constant, with a variable frequency. The audio signal should only play for 0.1 seconds before turning off. Additionally, the LED matrix should display the key pressed, as in Lab 6. In order to have a PWM signal and timer interrupts operating at the same time, Timer 11 (TIM11) will have to be configured in addition to Timer 10 (TIM10); refer to previous lab manuals to configure Timer 11. This program should start with a duty cycle of 0%, so no sound is produced. In your laboratory notebook, include a draft program (or direction to your content on H: drive).

Laboratory Experiments

1. Beginning this week, teams will need to design their own experiments to test designed hardware and software. Be sure to document each experiment in lab notebooks, and summarize the most significant ones in progress reports.
2. Construct and test circuits in stages, ensuring that each stage works properly before proceeding to the next stage.
    a. ***Double and triple check all power supply connections to prevent damage to any components.***
    b. Verify the desired PWM signal at the microcontroller output ***before*** connecting the signal to the speaker drive input.
    c. Verify the speaker drive operation with a dummy load (resistor), before connecting the actual speaker. Confirm that drive characteristics are similar to theoretical values.
3. Measure the voltage on both sides of the speaker with Channels 1 & 2 of the *Waveforms* Oscilloscope panel. Measure the highest recorded voltage at each node for the following configurations and print out screen shots for your lab notebook:
    a. Circuit shown in Figure 1
    b. Circuit shown in Figure 1 with diode polarity reversed
    c. Circuit shown in Figure 1 with two diodes: one as shown and one with its polarity reversed
4. An audio signal with an amplitude of 1 V_{DC} is very large for an 8-Ω speaker. Which of the three measured configurations produces the best sound? Which is the safest from an electrical (voltage and current) standpoint? Are any of these configurations safe for audio waveforms with long durations? (longer than 0.1 sec) Would placing a resistor in series with the speaker make the circuit 'safer'? What would it do to the sound?

Information for Future Laboratory Reports

1. Briefly describe the circuit (but not "wire by wire") and the test program (attach a circuit diagram and C program source listing).

2. Discuss your results, including a table of speaker voltage and current (assuming a load of 8-Ω) vs. diode configuration. Compare experimental and theoretical results, including what you observed at different PWM signal frequencies.