

(2 pts) Name: _____

AME 3623: Embedded Real-Time Systems: Final Exam

May 14, 2010

- This examination booklet has 17 pages.
- Do not forget to write your name at the top of the page and to sign your name below.
- The exam is closed book, closed notes, and closed electronic device. The exception is that you may have one page of your own notes.
- The exam is worth a total of 200 points (and 20% of your final grade).
- Explain your answers clearly and be concise. Do not write long essays (even if there is a lot of open space on the page). A question worth 5 points is only worth an answer that is at most 1.5 sentences.
- You have 2 hours to complete the exam. Be a smart test taker: if you get stuck on one problem go on to the next. Don't waste your time giving details that the question does not request. Points will be taken off for answers containing extraneous information.
- Show your work. Partial credit is possible, but only if you show intermediate steps.

Problem	Topic	Max	Grade
0	Name	2	
1	Interrupt Service Routines and Digital I/O	40	
2	Number Representation and Arithmetic	25	
3	Finite State Machines	40	
4	Device Control	25	
5	Sequential Logic	25	
6	Analog Processing	20	
7	Microprocessors	25	
Total		202	

On my honor, I affirm that I have neither given nor received inappropriate aid in the completion of this exam.

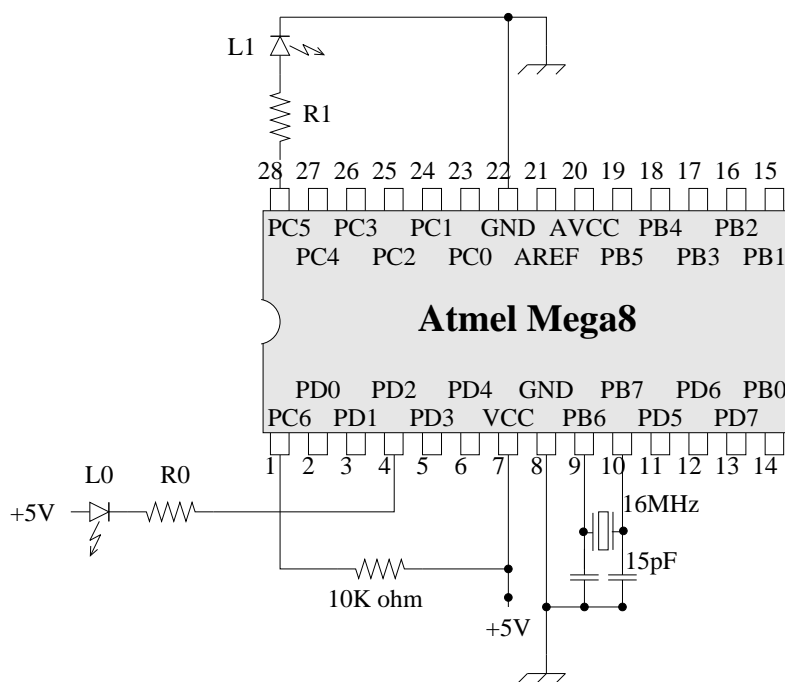
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Date: _____

1. Interrupt Service Routines and Digital I/O

(40 pts)

Carefully consider the following circuit:



Our goal is to write an ISR and supporting code that will do the following:

- Pulse LED L_0 with a pulse-width-modulated signal with a variable period and a fixed duty cycle of 25%.
- Pulse LED L_1 with a pulse-width-modulated signal with twice the period of L_0 and with a fixed duty cycle of 50%.
- When the period is changed (by the main program), the ISR should never produce a period that is longer than the max of the old and new periods (we call this behavior “glitch free”).
- The ISR may assume that $period > 0$.

The following is a first attempt at implementing this code:

```
volatile uint8_t period = 1;

ISR(TIMER2_OVF_vect) {
    static uint16_t counter = 0;

    if(counter == period)
        counter = 0;

    if(counter == 0) {
        PORTD |= 0x04;
        PORTC |= 0x40;
    }

    if(counter == (period>>3)) {
        PORTD &= ~0x04;
    }

    ++counter;
}

void set_period(uint8_t per) {
    period = per;
}

int main(void) {
    DDRD = 0x04;
    DDRC = 0x40;
    timer2_config(TIMERO_PRE_8);
    timer2_enable();
    sei();

    while(1) {
        set_period(10);
        delay_ms(2000);
        set_period(100);
        delay_ms(2000);
    }
}
```

- (a) (5 pts) Assuming a system clock of $16MHz$, at what frequency is the timer 2 counter incrementing?
- (b) (5 pts) At what frequency is the timer 2 overflow interrupt being generated? (yes, work out the long division by hand)
- (c) (5 pts) With $period = 100$, what is the intended flashing frequency of $L0$?
- (d) (20 pts) There are several bugs in the code implementation, correct these (do this on the previous page).

- (e) (5 pts) Suppose we were to instead use timer 1 in the above code, with a prescaler of 1. What is the period between interrupts? (yes, perform the long division).

2. **Number Representation and Arithmetic**

(25 pts)

(a) (5 pts) What is the binary equivalent of decimal 60? Show your work.

(b) (5 pts) What is the binary equivalent of decimal -60 (in 8-bit two's complement)? Show your work.

(c) (10 pts) Compute $0x32 - 60$ using binary arithmetic (give your answer in binary). Show your work.

(d) (5 pts) What is the decimal equivalent of the above result?

3. Finite State Machines and Control

(40 pts)

Consider the problem of a robot dribbling a ball down a soccer field until it reaches the far end of the field (we will call this *the goal*). The robot is equipped with a camera that will automatically move to follow the ball if it sees it. We will design a FSM that performs the high level control for this robot.

The actions are as follows:

- Search ball (SEARCH). This is a generic action that takes a variety of strategies to find the ball (and will ultimately succeed)
- Move toward location behind ball (BEHIND): the robot drives toward a position so that the ball is between the robot and the goal
- Approach ball (APPROACH): the robot drives directly to the ball
- KICK
- CELEBRATE

The events are:

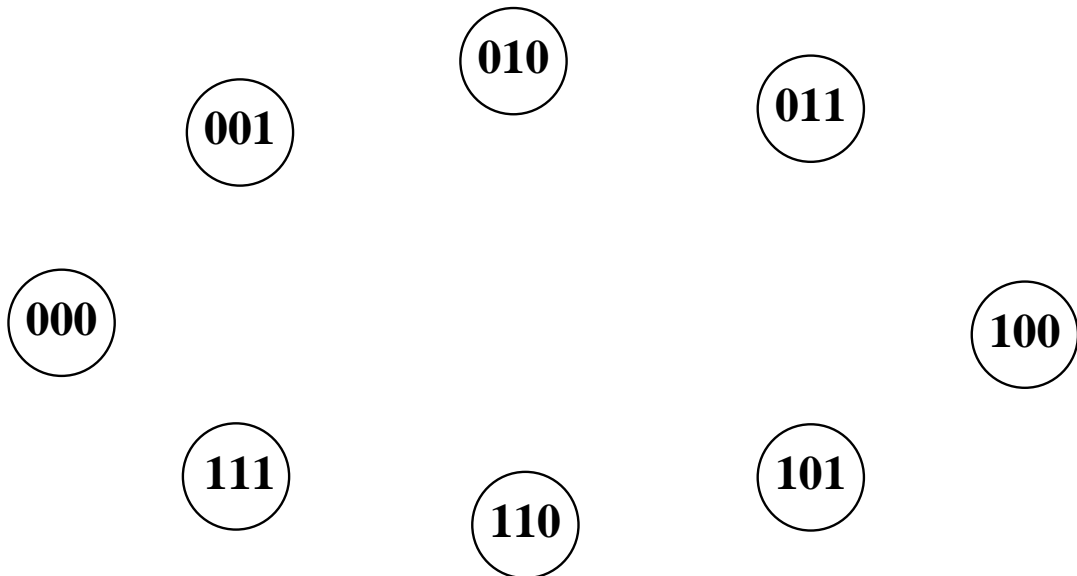
- FOUND: the camera sees the ball
- NOT_FOUND: the camera does not see the ball
- NEAR: the ball is very close to the robot
- GOAL: the ball is at the goal
- NOT_GOAL: the ball is not at the goal
- LINED_UP: the ball is between the robot and the goal

Note: Although the camera will move to try to keep the ball in view, it can lose visual track of the ball. The FSM must take this into account by initiating a new search.

- (a) (20 pts) Draw the FSM that will result in the ball arriving at the goal (and the robot celebrating this fact)

Consider a FSM whose state is described by a 3-bit two's complement binary number (i.e., there are 2^3 states). This finite state machine has two possible events: invert (INV) (take the two's complement inverse) and decrement (DEC) (subtract one).

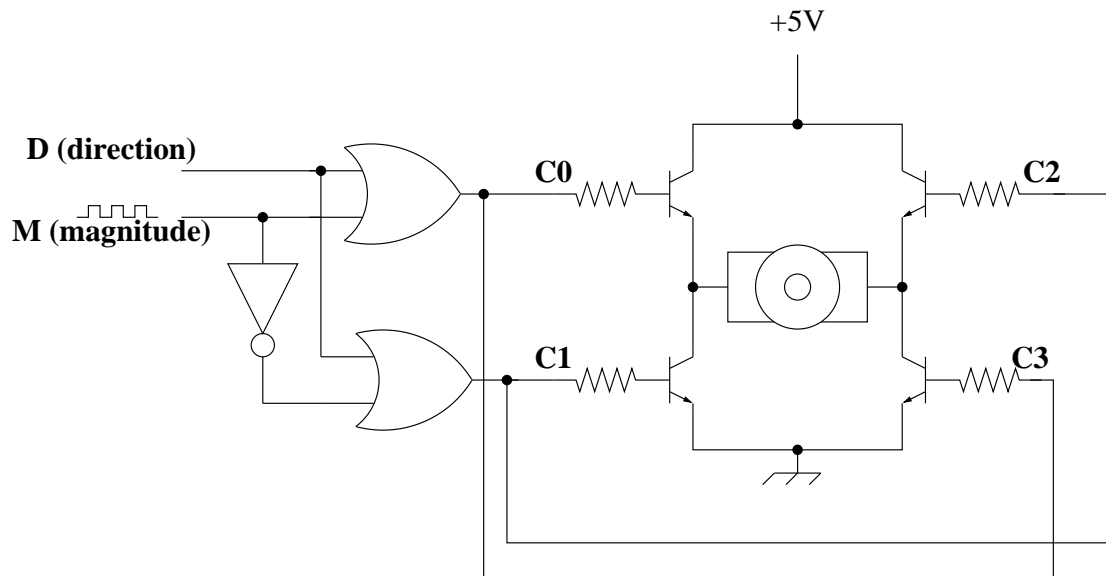
- (b) (20 pts) Draw the FSM diagram that describes the behavior of this device when the different events occur (don't worry about actions in this case).



4. Device Control

(25 pts)

Given the following H-bridge circuit:



D is a directional input that is intended to specify the direction of motor torque.

M is a Pulse Width Modulated signal that is intended to specify the magnitude of the torque signal (the higher the duty cycle, the higher the torque).

- (a) (10 pts) For the given circuit, what is the truth table for C_0 , C_1 , C_2 , and C_3 as a function of D and M ?

D	M	C_0	C_1	C_2	C_3
0	0				
0	1				
1	0				
1	1				

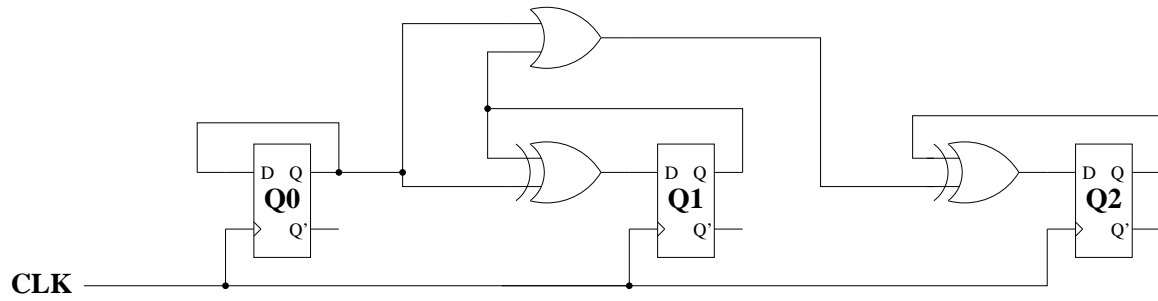
(b) (5 pts) Briefly describe what happens to the circuit when $D = 1$ and $M = 1$.

(c) (10 pts) The circuit has two bugs. What are they and how do you fix them?

5. Sequential Logic

(25 pts)

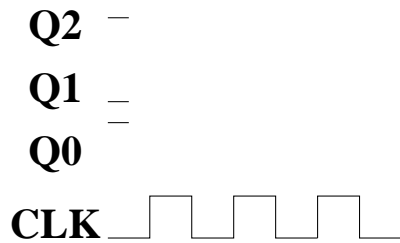
Consider the following circuit:



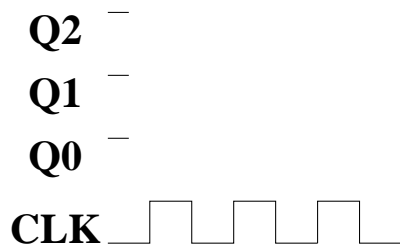
(a) (10 pts) Fill in the following truth table:

Q_2	Q_1	Q_0	D_2	D_1	D_0
0	0	0			
0	0	1			
0	1	0			
0	1	1			
1	0	0			
1	0	1			
1	1	0			
1	1	1			

- (b) (5 pts) Assuming an initial state of $Q_2, Q_1, Q_0 = 101$, fill in the following timing diagram:



- (c) (5 pts) Assuming an initial state of $Q_2, Q_1, Q_0 = 111$, fill in the following timing diagram:

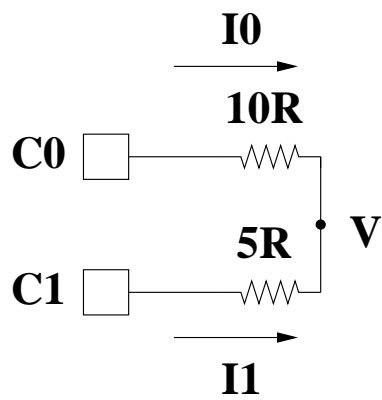


- (d) (5 pts) Interpreting Q_2, Q_1, Q_0 as a 3-bit number, what mathematical operation does this circuit perform when the clock changes from high to low? Your answer should apply to all possible combination of bits.

6. Analog Processing

(20 pts)

Consider the following digital-to-analog circuit:



C_1 and C_0 are bit values (i.e., 0 and 1). The voltage at pin i is $5C_i$.

- (a) (10 pts) Derive an equation for V as a function of C_1 and C_0 . Show your work.

(b) (10 pts) Interpreting C_1, C_0 as a 2-bit binary number, what is V for each of the following values (give the simplified ratio):

C	V
0	
1	
2	
3	

7. **Microprocessors**

(25 pts)

(a) (5 pts) Briefly explain the function of the address line inputs into a memory chip.

(b) (10 pts) List the conditions that must hold in order for a write operation to take place to a specific RAM memory element.

(c) (5 pts) Briefly explain the function of the *program counter*.

- (d) (5 pts) Briefly explain why Flash EEPROM is used to store the program on the Atmel Mega 8.