

Jonathan W. Valvano

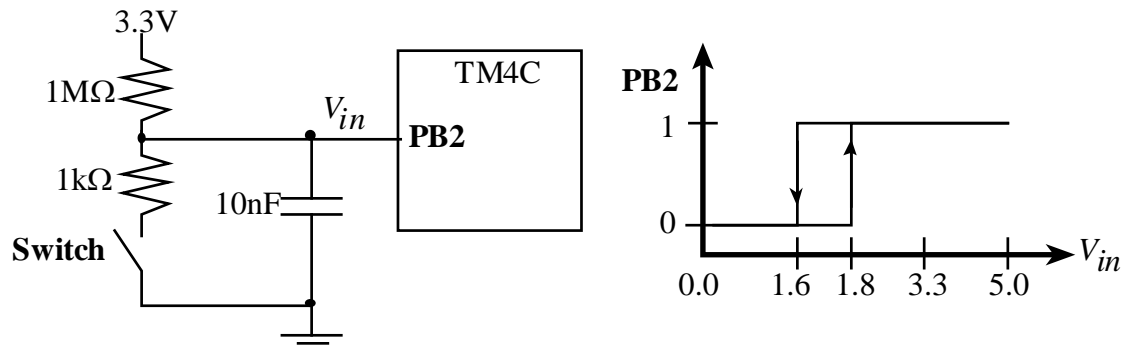
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Open book, open notes, calculator (no laptops, phones, devices with screens larger than a TI-89 calculator, devices with wireless communication). You must put your answers in these boxes. Please don't turn in any extra sheets or write on the back of the pages.

(10) Problem 25. The following circuit does debounce the switch if the bounce time is less than 1 ms. You may assume there is no current into the **PB2** input pin on the TM4C123. The relationship between analog input V_{in} and the corresponding effective digital value was measured as shown in the graph. You may assume the switch is ideal, with 0 or infinite resistance when touched or releases respectively.



(bonus) Part a) Assume the switch has been released for a long time and is touched at $t=0$.

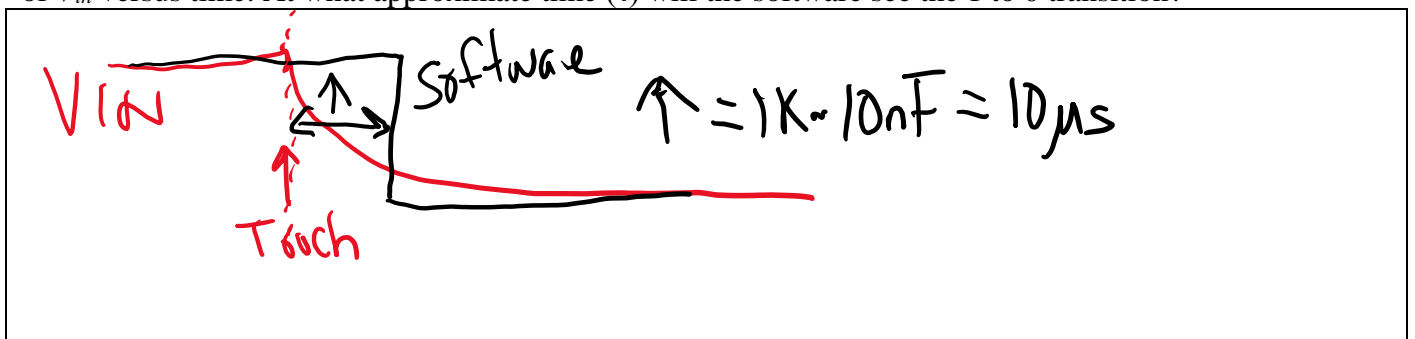
What is the instantaneous current through the switch at $t=0$?

$$I(0) = 3.3V / 1k = 3.3mA$$

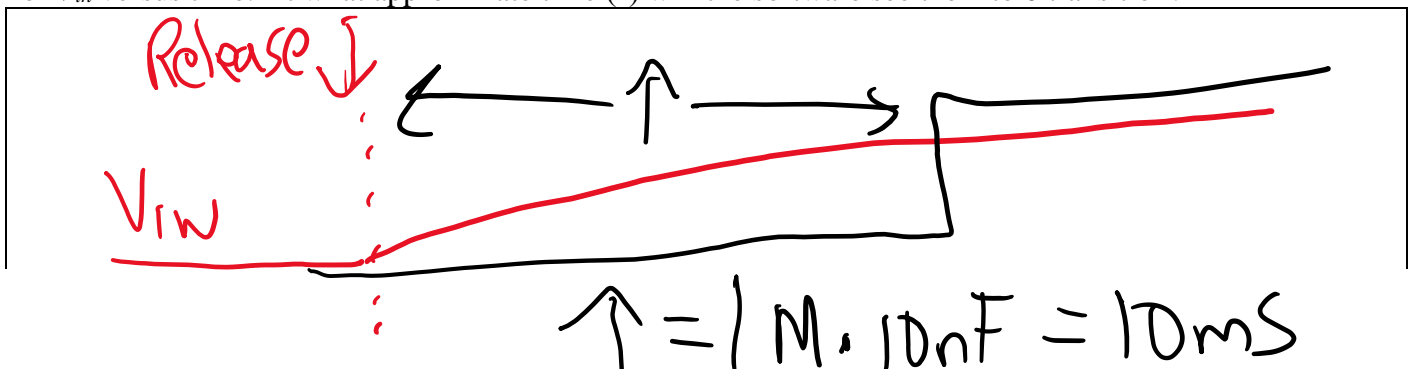
What would happen to the switch if the $1k\Omega$ were replaced with 0Ω ?

$$I(0) = \text{infinite} \Rightarrow \text{spark}$$

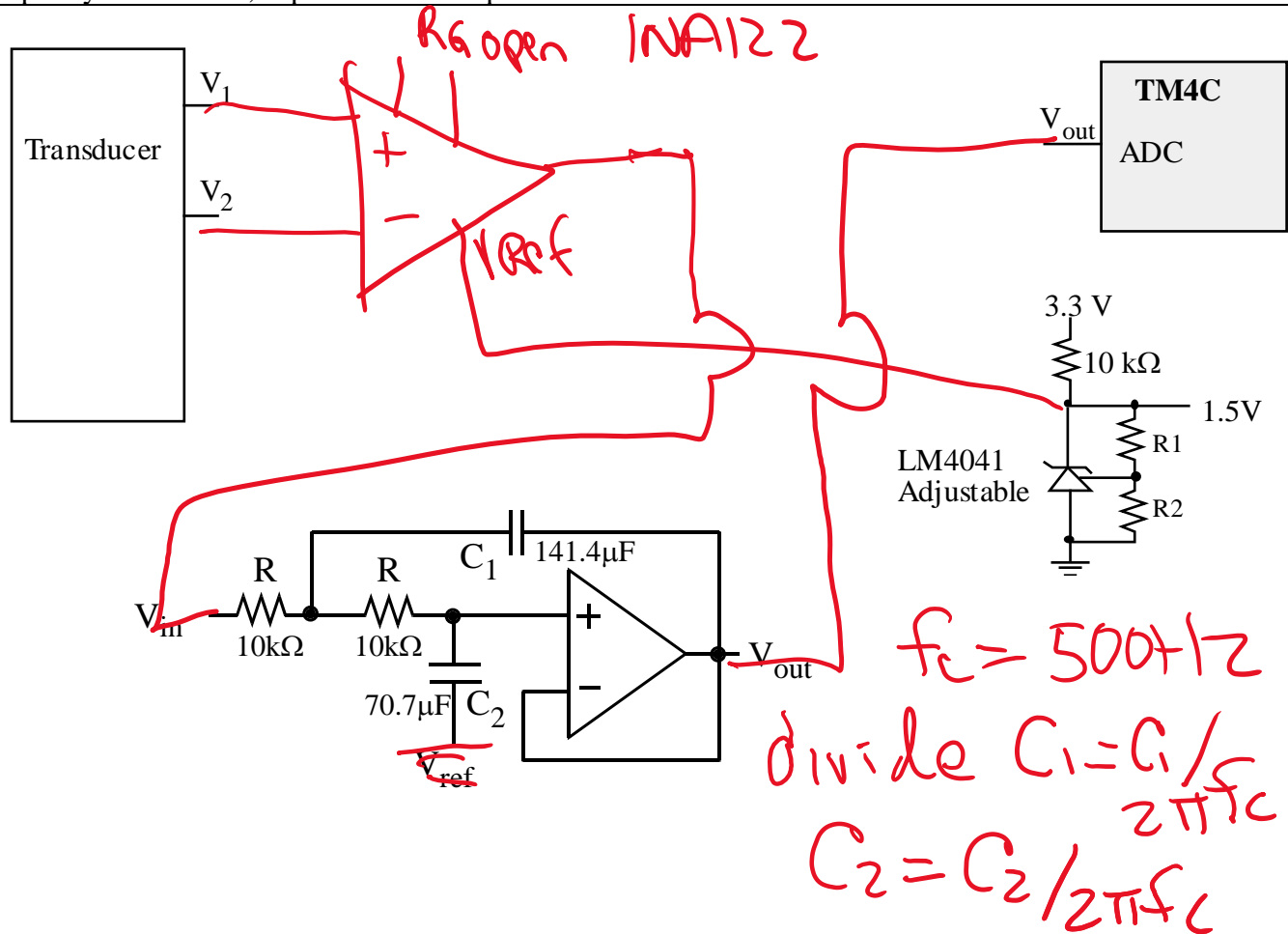
(5) Part b) Assume the switch has been released for a long time and is touched at $t=0$. Make a rough sketch of V_{in} versus time. At what approximate time (τ) will the software see the 1 to 0 transition?



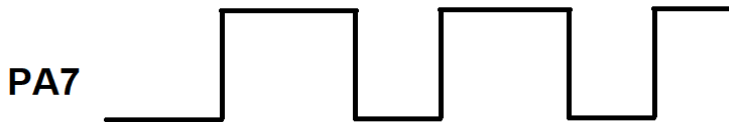
(5) Part c) Assume the switch has been touched for a long time and is released at $t=0$. Make a rough sketch of V_{in} versus time. At what approximate time (τ) will the software see the 1 to 0 transition?



(10) Question 26. Design an analog circuit that has two inputs and one output, such that the output is $5*(V_1 - V_2) + 1.5$. The input voltages are constrained to 0 to 3.3V. Assuming the sampling rate is 1000 Hz, add an appropriate analog filter. The only available power supply voltage is 3.3V. Assume R_1 and R_2 are already chosen to achieve a reference of 1.5V. Please use one or more op amps. Show design steps, and specify all resistors, capacitors and chip numbers.



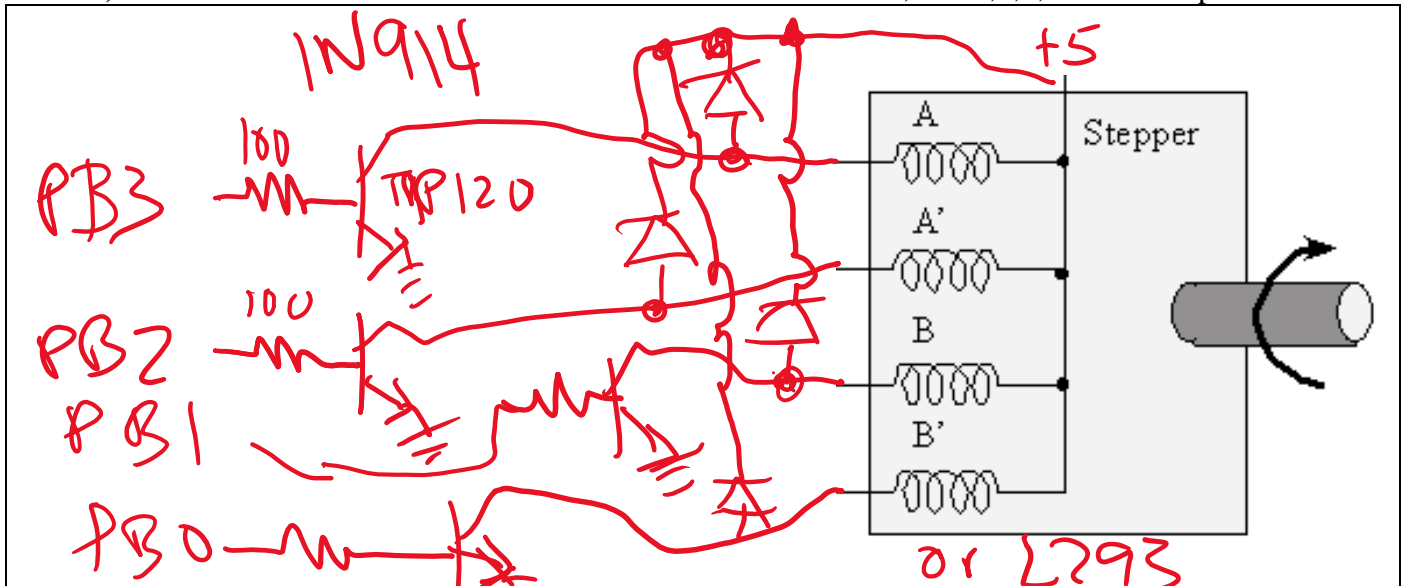
(10) **Question 27.** Assume there is an input connected to PA7 and assume PA7 is already initialized as an input. PA7 has a periodic squarewave on it. In this question, there are NO timers, NO SysTick, NO input capture, and NO interrupts. I.e., PA7 is a simple GPIO input. Write a **function in C** that measures the period of the input squarewave on PA7. Your function will measure the period once and return the result. In your comments estimate the precision and resolution of this measurement. The bus clock frequency is 80 MHz. A simple line of C code takes about 10 bus cycles or 125ns to execute. Hint: basically, I am asking you to implement input capture period measurement without the timers and without interrupts.



```
uint32_t PeriodMeasure(void)
// resolution is 250ns, precision is 32 bits
uint32_t count=0;
while((GPIO_PORTA_DATA_R&0x80)==0){} // wait for rise
while((GPIO_PORTA_DATA_R&0x80)!=0x80){ // wait for fall
    count++; // 2 lines of C is about 250ns
}
while((GPIO_PORTA_DATA_R&0x80)==0){ // wait for rise
    count++; // 2 lines of C is about 250ns
}
return count;
}
```

(10) Question 28. Interface a unipolar stepper DC motor to the TM4C123. The desired voltage is 4 to 5 V, and the expected current is 0.05 to 0.1A. There are 4 coils, labelled A, A', B and B'. The software should output the binary sequence 0101,0110,1010,1001 (5,6,10,9) over and over to spin the motor. Each output (e.g., changing 5 to 6) causes one step. Since there are 200 steps per rotation if the software outputs one new value every 5ms, the motor will spin at 1 rps.

Part a) Show the electrical circuit that interfaces the motor to Port B, bits 3,2,1,0. Label all parts.



Part b) Write software that spins the motor at 1 rps using interrupts. Your solution will have an initialization, which will be called once, and an interrupt service routine, which will be called periodically. You do not need to show the main program, which will call your initialization and then perform other unrelated tasks. Full credit if there are no **for**, **while**, **if** or **switch** statements.

```
static uint32_t Index;
#define Bus 16000 // frequency in kHz
const uint32_t Out[4]={5,6,10,9};
void Init(void){ Index=0;
    SYSCTL_RCGCGPIO_R |= 0x02;
    NVIC_ST_CTRL_R = 0x07
    NVIC_ST_RELOAD_R = 5*Bus-1;
    GPIO_PORTB_DIR_R |= 0x0F; // make PB3-0 out
    GPIO_PORTB_DEN_R |= 0x0F; // enable digital I/O on PB3-0
    EnableInterrupts();
}
void SysTick_Handler(void){ // every 5ms
    GPIO_PORTB_DATA_R = (GPIO_PORTB_DATA_R&0xF0)+Out[Index];
    Index = (Index+1)&0x03; // 0,1,2,3
}
```

(2) **Question 1.** Which protocol **UDP** or **TCP** provides the fastest bandwidth at the expense of reliability?

(4) **Question 2.** Implement this low pass digital filter. These shared global variables have data `int32_t x,y;`

Other software, such as an ISR, will enter data into the variable. Write a C code that calculates

$$y = 0.875*y + 0.125*x$$

using **binary fixed point math**. No floating point allowed. Prevent overflow assuming both x,y range between -10000 to +10000. Minimize the effect of dropout. The system executes your code at a regular rate.

(2) **Question 3.** Give one **regulator** type that uses an **inductor** to operate.

Buck, boost, buck-boost

(2) **Question 4.** Consider **capacitor** types used in this class. Give one capacitor type that has a **small leakage current**? I.e., if you place charge on the capacitor, which type holds the charge for a long time?

Ceramic

(2) **Question 5.** What **software change** can you make to reduce pollution (carbon emissions) on the planet?

PU to shutdown or wait for interrupts

(2) **Question 6.** What are the units of **ADC precision**?

bits or alternatives

(2) **Question 7.** What **physical entity** is used to **communicate** information across distance?

energy

(2) **Question 8.** If the average rate at which one puts into a FIFO (producer) is slower than the average rate at which the system can process data (consumer), **can the FIFO ever get full**? Answer a yes or no.

(2) **Question 9.** Give the equation for **Little's Theorem**. Define all terms in the equation.

Let N be the average number of data packets in the queue plus the one data packet currently being processed by the consumer. Basically, N is the average number of packets in the system. Let λ be the average arrival rate in packets per second (pps). Let R be the average response time of a packet, which includes the time waiting in the queue plus the time for the consumer to process the packet. **Little's Theorem** states

$$N = \lambda R$$

(2) **Question 10.** Give the equation for the **Shannon-Hartley Channel Capacity Theorem**. Define all terms in the equation.

The channel bandwidth W in Hz and the SNR is the signal to noise ratio (units watts/watt)

$$C = W \cdot \log_2(1 + SNR)$$

(4) **Question 11.** Give an equation for the **power budget** for an embedded system. Define all terms in the equation.

Total battery storage (A-hr) = Average system current(A)*lifetime of system(hr)

(2) **Question 12.** A signed 8-bit integer is used with a **binary fixed point** number system. The resolution is 2^{-4} cm. What is range of values that can be represented? Give units.

$$\text{Min} = -128/16 \text{ cm} = -8 \text{ cm}, \quad \text{Max} = 127/16 \text{ cm} = +7.9375 \text{ cm}$$

(2) **Question 13.** An unsigned 16-bit integer is used with a **decimal fixed-point** number system. The maximum distance that needs to be stored is 10 cm. What is the smallest resolution possible? Give units.

$$65.535 = 65535 * 0.001 \text{ cm} > 10 \text{ cm}, \text{ so } 0.001 \text{ cm}$$

(2) **Question 14.** Which DAC architecture (binary weight, successive approximation, flash, R-2R, sigma-delta, or resistor string) is least likely to be **non-monotonic**? Give one answer. **resistor string**

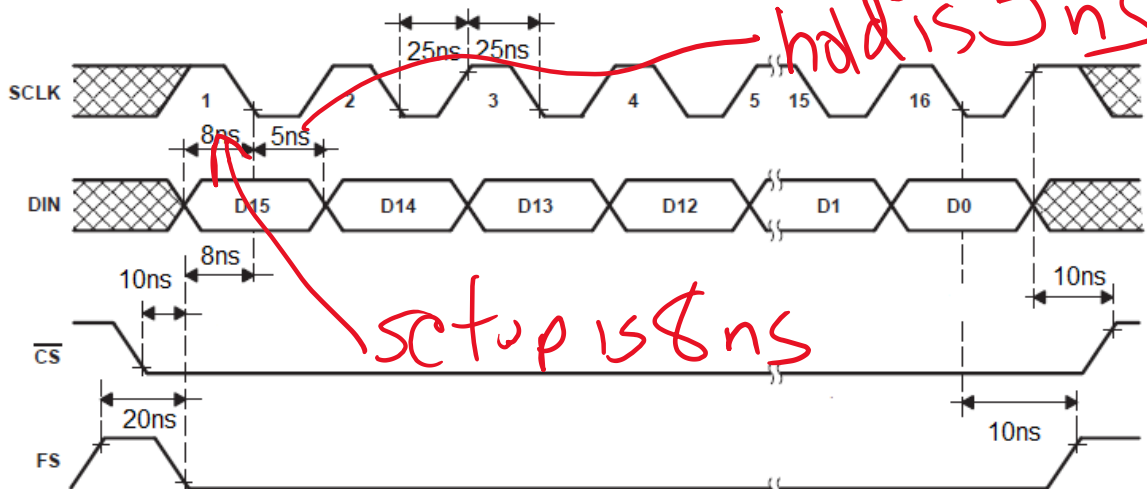
(2) **Question 15.** What is the precision of PWM output shown in Question 24? Give units

$$251 \text{ alternatives or } 8 \text{ bits}$$

(2) **Question 16.** How does the return from interrupt instruction **BX LR** change context?

- A) gets the PC value from vector table
 B) gets the PC value from RAM table
 C) simply moves LR to PC
 D) pops 0xFFFFFFFF off stack, then pops 8 more
 E) it does not move LR to PC, rather it pops 8 values
 F) pops the return address off stack into PC

Question 17. Consider this timing diagram from the DAC5616

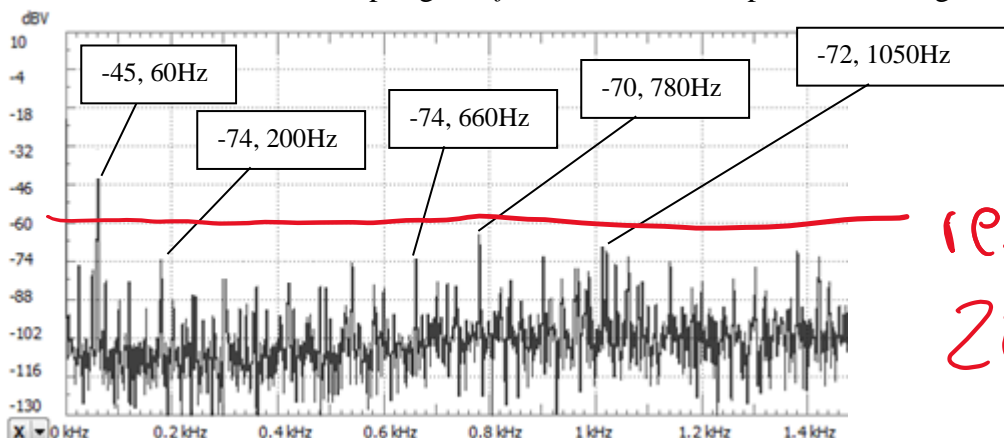


- (2) **Part a)** What is the setup time for the TLV5616? Give the number in ns.
 (2) **Part b)** What is the hold time for the TLV5616? Give the number in ns.

(2) **Question 18.** UART can use simple 3.3V/0V digital encoding or RS232 NRZ encoding with -6V/+6V outputs. What is the advantage of RS232 NRZ over simple 3.3V/0V digital encoding?

- A) no advantage
 B) less EMI emissions
 C) it is differential
 D) both high and low use energy so works longer distances
 E) it can drive less current
 F) faster because the capacitance is less

(4) **Question 19.** Consider a real-time data acquisition system with a 10-bit ADC sampled at f_s . Hint: 1024 is approximately 1000. First, calculate the ADC resolution in dB_{FS} . The following data were sampled at the input of the ADC. The desired signal exists in the 0 to 1 Hz range, and the rest of what you see in this spectrum is noise. Yes, it needs an analog filter. However, if you were to sample this signal exactly like this, what is the slowest sampling rate f_s allowed that will prevent aliasing? Show your work.



$$f_s > 60\text{Hz} \times 2 \times 2 = 120\text{Hz}$$

$$\begin{aligned} \text{resolution} &= 20 \log_{10} \frac{1}{1024} \\ &\approx 20 \log_{10} \frac{1}{1000} \\ &= -60 \text{ dB} \end{aligned}$$

Question 20. Consider the lab 10 system used to control motor speed. Choose the one best answer from the following A-F for both parts a) and b).

- | | |
|-------------------------------------|-----------------------------------|
| A) Reduces controller error | D) Reduces sensor noise |
| B) Reduces controller response time | E) Faster for software to execute |
| C) Reduces cost | F) Requires less memory |

(2) **Part a)** In what way is a I controller better than a P controller? **A**

(2) **Part b)** In what way is a PI controller better than just a I controller? **B**

(2) **Question 21.** There are ten points of the IEEE Code of Ethics. Which one of the following points is not one in the IEEE Code of Ethics?

1. to ~~accept responsibility~~ consistent with the **safety, health and welfare** of the public;
2. to ~~recognize~~ real or perceived **conflicts of interest** whenever possible, and to hide them;
3. to be **honest and realistic** in stating claims or estimates based on available data;
4. to **reject bribery** in all its forms;
5. to **improve the understanding of technology**, its application, and consequences;
6. to **maintain and improve our technical competence**;
7. to **seek, accept, and offer honest criticism** of technical work, to acknowledge and correct errors;
8. to **treat fairly all persons**;
9. to **avoid injuring others**, their property, reputation, or employment **by false or malicious action**;
10. to **assist** colleagues and to **support them in following this code of ethics**.

(4) **Problem 22.** Consider the following SysTick interrupting system with its corresponding assembly code. You may assume SysTick interrupts occur slowly enough that SysTick will not attempt to interrupt itself. The listing includes absolute addresses. ROM exists from 0x00000000 to 0x0003FFFF. RAM exists from 0x20000000 to 0x20007FFF. At the time **Output** is called, R0 contains n, R1 contains p.

```
#define PF2 (((uint32_t *)0x40025010))
#define PF1 (((uint32_t *)0x40025008))
void static Output(int32_t n, uint32_t *p){
    static int32_t i;
    for(i=4; i; i--){
        *p = n;
        *p = 0;
    }
}

void SysTick_Handler(void){
    Output(4,PF2);
}

int main(void){
    Init(); // includes SysTick_Init
    EnableInterrupts();
    while(1){
        Output(2,PF1);
    }
}
```

remove static

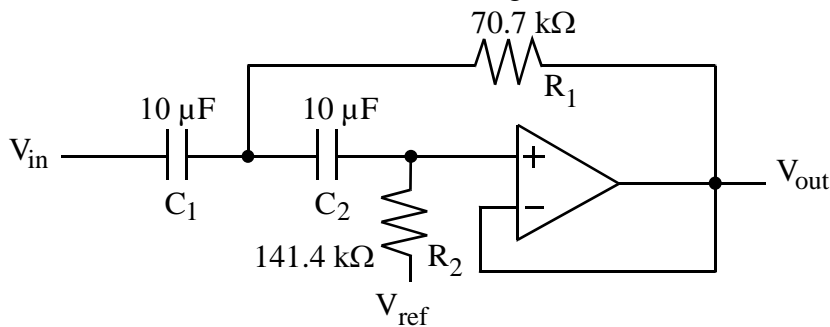
```
Output:
0x000003C4      LDR    r2,=0x20000000
0x000003C6      MOV    r3,#4
0x000003C8      STR    r3,[r2],i=4
0x000003CA      MOV    r12,#0
0x000003CC loop  LDR    r3,[r2]
0x000003CE      CMP    r3,#0
0x000003D0      BEQ    done ;quit if i=0
0x000003D2      STR    r0,[r1];*p=n
0x000003D4      STR    r12,[r1];*p=0
0x000003D6      LDR    r3,[r2]
0x000003D8      SUB    r3,#1
0x000003DA      STR    r3,[r2];i--
0x000003DC      B      loop
0x000003DE done  BX     lr
SysTick_Handler:
0x000004C4      PUSH   {lr}
0x000004C6      MOV    r0,#0x04
0x000004C8      LDR    r2,=0x40025010
0x000004CA      BL     Output
0x000004CC      POP    {pc}
main:
0x00000510      BL     Init
0x00000514      BL     EnableInterrupts
0x00000518 loop  MOV    r0,#0x02
0x00000518      LDR    r1,=0x40025008
0x0000051E      BL     Output
0x00000522      B      loop
```

write read write

There may be other code that accesses bits 4,3,0 of Port F, but there is no other code that accesses bits 2,1 of Port F. Is there a critical section? If so, how would you solve this critical section? Your solution must maintain overall function of the system, such that the output is toggled 4 times.

- ~~A) Add the **volatile** to the definition of **i**~~
- B) Remove the **static** from the definition of **i****
- C) Disarm SysTick and rearm SysTick around the critical section(s)
- D) Remove the **EnableInterrupts** call from **main**
- E) Add **DisableInterrupts** at beginning and **EnableInterrupts** at end of **SysTick_Handler**
- F) Remove the **static** designation from the function **Output**
- G) Use regular access to Port F (not bit-specific addressing)
- H) Add the **const** to the definition of **n**
- I) Add the **volatile** to the definition of **n**
- J) There is a critical section, but none of the above will remove the critical section
- K) There is no critical section to remove, it runs without error

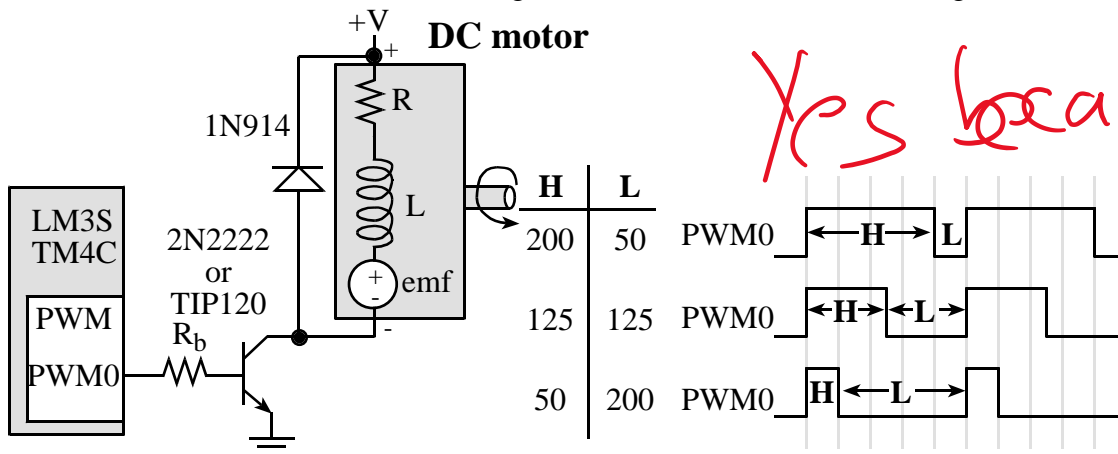
(2) **Question 23.** Consider the following circuit



In general, what type of circuit is the above analog circuit?

- A) Amplifier
- B) **Low-pass filter**
- C) High-pass filter
- D) Band-pass filter
- E) Threshold detector
- F) Inverter
- G) Integrator
- H) Voltage reference
- I) None of these

(2) **Question 24.** Consider the following circuit. Assume H and L are integers that always add to 250.



Yes because of emf

Assume +V is +5V. Let the PWM0 output be high, so the collector voltage of transistor is 0.5V. The transistor is fully in saturation. Is it possible for current to flow up from the collector into the +5V supply? Answer yes or no.