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Open book, open notes, open computer, calculator (wireless devices must be in airplane mode). Screens must not be visible to other students.

(10) Question 1. These two initializations are critical to each other, because they have read-modify-write nonatomic sequences with shared information. These are the definitions of the ports:

```
#define SYSCTL_RCGCGPIO_R  (*((volatile uint32_t *)0x400FE608))
#define GPIO_PORTE_DIR_R   (*((volatile uint32_t *)0x40024400))
#define GPIO_PORTE_DEN_R   (*((volatile uint32_t *)0x4002451C))
```

`void InitPE2(void){`
`volatile uint32_t delay;`
`  SYSCTL_RCGCGPIO_R |= 0x10;`
`  delay = SYSCTL_RCGCGPIO_R;`
`  GPIO_PORTE_DIR_R &= ~0x04; // PE2 input`
`  GPIO_PORTE_DEN_R |= 0x04;`
`}`
	`void InitPE3(void){`
	`volatile uint32_t delay;`
	`  SYSCTL_RCGCGPIO_R |= 0x10;`
	`  delay = SYSCTL_RCGCGPIO_R;`
	`  GPIO_PORTE_DIR_R &= ~0x08; // PE3 input`
	`  GPIO_PORTE_DEN_R |= 0x08;`
	`}`

(5) Part a) What is the basic idea of how to remove this critical section without disabling interrupts, changing where/when they are called, or moving the input to another port?

(5) Part b) Rewrite the two functions (show C code), removing the critical section.

(10) Question 2. The following ADC sampling occurs in this high priority 10kHz periodic ISR. The desired sampling rate is 10 kHz. The ADC is set at maximum speed, so the while loop requires about 1us to execute with SAC=0 (one sample). With SAC=0, this FIFO queue never gets full.

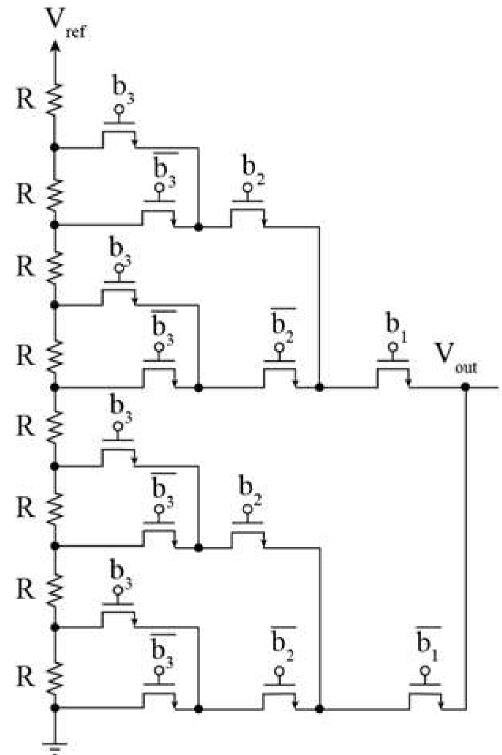
```
void Timer2A_Handler(void){
  TIMER2_ICR_R = 0x01;
  ADC0_PSSI_R = 0x0008;
  while((ADC0_RIS_R&0x08)==0){};
  FIFO_Put(ADC0_SSFIFO3_R);
  ADC0_ISC_R = 0x0008;
}
```

(4) Part a) To improve SNR, SAC was increased to 6 (64-sample averaging). This one change caused the FIFO to get full. Why did it fail?

(3) Part b) How would you fix it, so the ADC still samples at 10 kHz with SAC=6? First, explain how you would change the initialization of the ADC and interrupts.

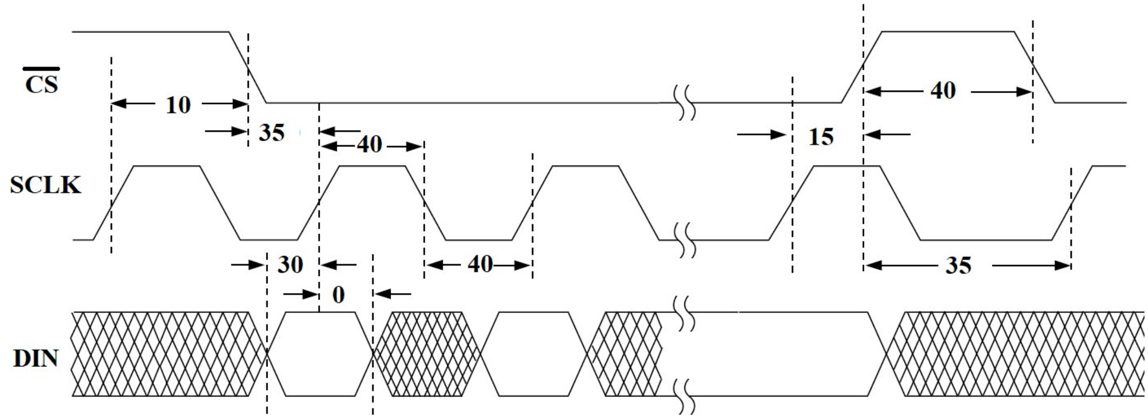
(3) Part c) Show the C code for the new ISR, but no code is needed for changes to initialization.

(5) Question 3. The following is a broken 3-bit **resistor string** DAC. If there is nothing connected to V_{out}, the output is a linear function of the binary input b_3,b_2,b_1, with a range of 0 to V_{ref}. However, if we connect V_{out} to another circuit, the output voltage drops a lot and is no longer linear. Redesign (fix) this broken circuit, so the output is linear when connected to other circuits.



(10) Question 4. You are evaluating possible PID controllers for your design. To compare the various choices, you need a **figure of merit (FOM)**, which is a single number that combines all the performance metrics that matter to you. Create a FOM with at least **3 components to it**, such that the bigger the FOM the better the controller, avoid calculations of infinity as FOM. Explain each component and give units for each. Draw figures to explain as necessary.

(10) Question 5. Consider this timing diagram for the MAX549A 8-bit DAC. You are asked to interface this DAC to pins PB7, PB6, PB5, and/or PB4 using SSI2.



(2) Part a) What is the setup time for the MAX549A? Give the number in ns.

Setup =

(2) Part b) What is the hold time for the MAX549A? Give the number in ns.

Hold =

(2) Part c) To which TM4C123 pin (PB7, PB6, PB5, or PB4) would you connect CS?

Connect CS to

(2) Part d) To which TM4C123 pin (PB7, PB6, PB5, or PB4) would you connect SCLK?

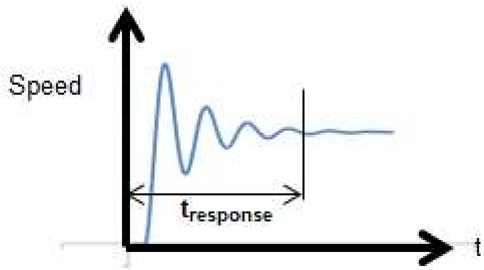
Connect SCLK to

(2) Part e) To which TM4C123 pin (PB7, PB6, PB5, or PB4) would you connect DIN?

Connect DIN to

(5) Question 6. Consider a N-point DFT, which was sampled at $\mathbf{f_s}$. The output of the DFT is an array of complex numbers with index **k** that ranges from 0 to **N**-1. For **k** < ½ **N**, give the relation between the index **k** and the equivalent frequency for the array value at index **k**.

(10) Question 7. rps is the measured speed. **Xstar** is the desired speed. The PI controller has this response (**rps** versus time) to a change in setpoint, **Xstar**. **Kp** and **Ki** are controller constants. The software runs at a constant rate of 100 Hz.




```
E  = Xstar-rps;
P  = (Kp * E)/4096;
P  = max(300,min(39990,P));
I  = I + (Ki * E)/4096;
I  = max(300,min(39990,I));
U  = P + I;
U  = max(300,min(39990,U));
PWM0A_Duty(U);
```

(5) Part a) To improve the response, which would you change **Kp** or **Ki**?

(5) Part b) Would you increase its value, decrease its value, or change its sign?

(10) Question 8. Consider the following **frequency measurement** performed on PE0 input using edge-triggered and periodic interrupts. The edge-triggered ISR is invoked on each rising edge of PE0. The timer interrupt occurs every 10 ms. You may assume the bus clock is 80 MHz. ISRs have equal priorities.

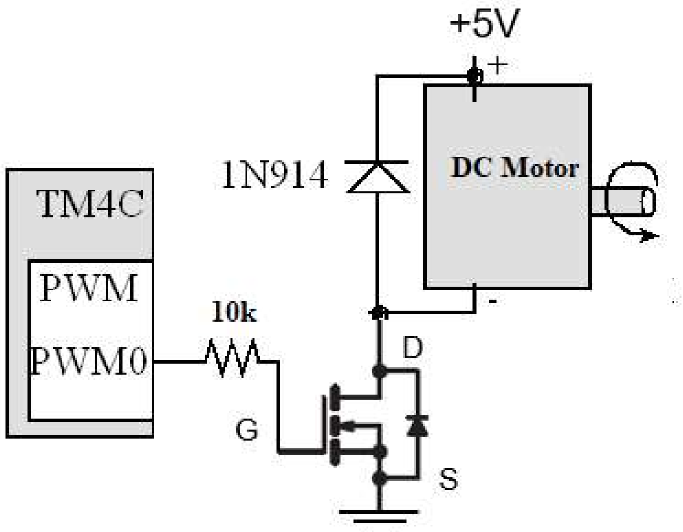
```
uint32_t Count,Freq;
void GPIOPortE_Handler(void){
  GPIO_PORTE_ICR_R = 0x01;
  Count++;
}
```

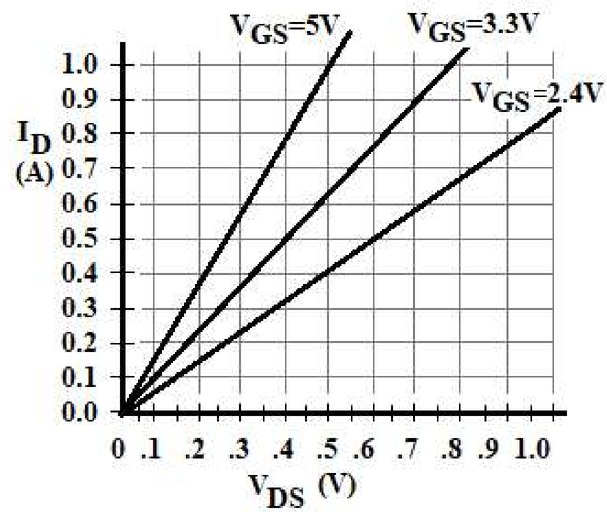
```
void Timer2A_Handler(void){
  TIMER2_ICR_R = 0x01;
  Freq = Count;
  Count = 0;
}
```

(5) Part a) What is the **frequency measurement resolution**? Give units

(5) Part b) Estimate the **frequency measurement range**. Give minimum and maximum values.

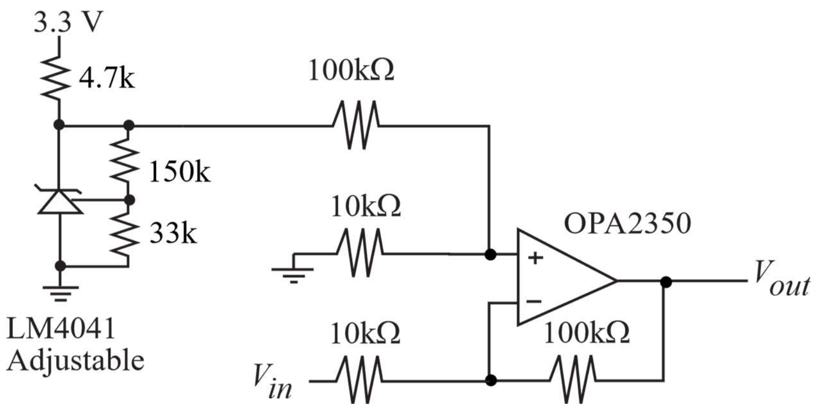
(10) Question 9. Consider motor interface powered by 5V and a MOSFET. When 4 to 6V is applied directly across the motor, the current is about 0.5A. When the MOSFET is disconnected from the microcontroller, the output voltage, V_{OH}, is 3.3V. At a maximum I_{OH} of 8mA, the V_{OH} will be 2.4V. Estimate the power (in watts) applied to motor when the PWM duty cycle is 25%. Show your work.





(5) Question 10. You have a wired communication channel (e.g., UART, CAN, Ethernet, I2C, SPI), which could run at a maximum of **F** bps. The channel allows the sender and receiver to negotiate the actual speed, which might be less than or equal to **F** bps. Give at least three reasons might you want to negotiate a slower speed than the maximum **F**?

(10) Question 11. Derive the equation relating V_{out} to V_{in}, show your work. You may assume V_{out} remains 0 to 3.3V, and the OPA2350 is powered by 3.3V.



Bonus Question: When Valvano does this, to what embedded system concept is he referring?