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This is the closed book section. You must put your answers in the boxes. When you are done, you turn in the closed-book part and can start the open book part.

(4) Question 1. Using the term PMF, give an example of how the Central Limit Theorem applies to embedded systems. 

You did this in Lab 2

The probability mass function (PMF) plots the number of occurrences versus ADC output for a constant input. The CLT states that the noise process of a random signal approaches a Gaussian as more and more data are averaged. Example: when performing hardware averaging ADC data (SAC register in the ADC) the shape of the probability mass function (PMF) becomes Gaussian-shaped as the size if the averaging increases. Example: when implementing an averaging digital filter the shape of the PMF becomes Gaussian-shaped as the size of average increases.

(4) Question 2. What is the advantage of a +6V/-6V NRZ communication protocol over simple 3.3V/0V digital encoding? +6/-6V NRZ is RS232. Data is encoded as energy. The more energy the faster it is.

A) no advantage  D) both high and low use energy so it has a larger diameter
B) less EMI emissions  E) it can drive less current
C) it is differential  F) faster because the capacitance is less

Diameter is the maximum distance of the communication. RS232 goes farther than simple digital.

(5) Question 3. Consider the differences between tantalum and ceramic capacitors. Pick the answer that best differentiates the two capacitor types. Place a T for tantalum, a C for ceramic, a B for both, or an N for neither.

A) Which capacitor is nonpolarized? ---------------------------------------------------------------

Ceramic capacitors are not polarized, tantalum have a positive and negative side

B) Which capacitor has a larger ESR? -------------------------------------------------------------

Tantalum capacitors have a significant equivalent series resistance

C) Which capacitor should we use for precision high-frequency analog filters? ---------------------

Classic use of precision (C0G) ceramic capacitors

D) Which capacitor should we use for precision high-frequency digital filters? ----------------------

Trick question: software does not need capacitors

E) Which capacitor should we use between 3.3V power and ground? -------------------------------

Tantalum for high-amplitude low-frequency noise, and ceramic for high-frequency noise

(4) Question 4. There are ten points of the IEEE Code of Ethics. Which of the following points is not one of the ten points?

1. to give responsibility consistent with the safety, health and welfare of the public; (take responsibility)
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose 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.

I
(4) Question 5. Consider these ADC performance parameters:

A) linearity   B) accuracy   C) resolution
D) bandwidth   E) monotonicity  F) repeatability
G) precision

Listed here are experimental procedures one might use to measure ADC performance. State the ADC parameter determined by each procedure. There is one best answer. Place one letter A to G into each box.

Part a) The input is slowly changed from minimum to maximum. The input voltage, \( V_i \), that causes a change in digital output is recorded. The average of the differences \( V_{i+1} - V_i \) is calculated. **Resolution** is the smallest difference in input that can be detected. **C**

Part b) The input is slowly changed from minimum to maximum. The input voltage, \( V_i \), that causes a change in digital output is recorded. The number of \( V_i \) recordings is calculated. **Precision** is the number of different inputs that can be measured. **G**

Part c) The input is held constant, and the digital output is recorded multiple times. The standard deviation of these recordings is calculated. **Repeatability** is a measure of the noise, or variability in measurements. **F**

Part d) The input is slowly changed from minimum to maximum. The input voltage, \( V_i \), that causes a change in digital output is recorded. A linear regression is performed on the input/output data set. What ADC parameter does the correlation coefficient of this regression represent? **Linearity** is a measure of the straightness of the output versus input response. **A**

(10) Question 6. Consider an interrupt-driven data flow problem. The arrival of data triggers an input interrupt. The input ISR reads the data, puts them into a FIFO, and arms the output device. Reading data acknowledges the input interrupt. The output ISR is triggered when the output device is idle and it is armed. The output ISR gets data from the FIFO and if there are data the output ISR writes the data to the output. Writing data acknowledges the output interrupt. Both ISRs are running at the same priority and the main program is doing other unrelated tasks.

(5) Part a) What should you do if the input ISR gets a full error when calling FIFO put?

A) disarm the input ISR   B) disarm the output ISR   C) discard data
D) increase the size of the FIFO   E) decrease the size of the FIFO   F) none of the above

Some systems allow the software to dynamically increase/decrease FIFO size using the heap. If you disarm the input ISR then you will get no more input (nowhere else it the input rearmed). E) decreasing the size makes it worse

(5) Part b) What should you do if the output device gets an empty error when calling FIFO get?

A) disarm the input ISR   B) disarm the output ISR   C) discard data
D) increase the size of the FIFO   E) decrease the size of the FIFO   F) none of the above

You cannot choose A) because input stops occurring and the output occurs over and over. You cannot choose C) because the FIFO was empty and there is no data to discard. The FIFO is empty so increasing or decreasing the size has no effect.

(14) Problem 7. Consider the following Systick interrupting system with its corresponding assembly code generated by the Keil uVision compiler. You may assume Systick interrupts occur every 1 ms. The listing includes absolute addresses. ROM starts at 0x00000000, and RAM starts at 0x20000000. **Count** is a 32-bit variable at address 0x20000000. Notice the time to run the ISR (about 1µs) is much less than the time between interrupt triggers (1ms).
volatile uint32_t Counts = 0;

void static Add(uint32_t n){
    Counts = Counts + n;
}

void SysTick_Handler(void){
    Add(1);
}

int main(void){
    Init();
    EnableInterrupts();
    while(1){
        WaitForInterrupt();
        Add(-1);
    }
}

(4) Part a) Is there a critical section in the software system shown above?
   A) no critical sections  D) yes, access to Counts in main
   B) yes, with LR        E) yes, access to Counts in SysTick_Handler
   C) yes, access to R0   F) yes, access to Counts in Add

   Interrupts are always triggered during the WFI instruction

(2) Part b) What is the value of R2 at the end of executing Add?

   The contents of 0x000003D0 is loaded into R2, which is the address of Counts

(2) Part c) What is the low-power feature used in this system?

   WFI enters low power mode; while waiting the processor sleeps

(2) Part d) What does the volatile qualifier for Counts mean?
   A) private in scope      D) the value is fixed and cannot be changed by the function
   B) stored in ROM         E) tells the compiler to fetch a new value, and do not optimize
   C) stored in global RAM  F) promoted to the next high precision

   volatile turns off the optimization

(2) Part e) What does the static qualifier for the function Add() mean?
   A) function is public in scope      D) the parameters are fixed and cannot be changed
   B) function is stored in ROM        E) function is stored in RAM
   C) run with interrupts disabled     F) none of the above

   static makes the function private to this file; public in scope means any software count access

(2) Part f) How does the return from interrupt instruction POP {pc} change context?
   A) gets the PC value from vector table      D) pops 0xFFFFFFFF9 off stack, then pops 8 more
   B) gets the PC value from RAM table        E) tries to move LR to PC, then pops 8 values
   C) moves PC to LR, then pops 8 values      F) pops the return address off stack into PC

   The LR is 0xFFFFFFFF9 at the beginning of the ISR to signify this is an interrupt
(5) **Question 8.** This problem addresses the issue of capacitive loading on a high-speed serial transmission line like SSI. The SSI port of a TM4C123 is connected via a long cable to a DAC. We will model this cable as a single resistor in series with a capacitor, as shown on the left figure below. Consider a 3.3-V 1 MHz clock from the microcontroller to the DAC. The figure on the right plots the output of the microcontroller, labeled PA2.

Assume the SCLK has been low for a long time while the SSI has been idle and the clock begins to oscillate at time 0, as data is being transferred at 500 kHz. Develop an equation for the SCLK input at the DAC as a function of time for the time-region 0 to 1 μs. Use the equation to make a rough guess (without a calculator) about the voltage of the DAC input at time equals 1 μs.

This is a common interview question
Initially, the C is a short, so \( V_{\text{out}}(0) = 0 \).
At infinite time, the C is an open so, \( V_{\text{out}}(\infty) = 3.3 \text{V} \).

\[
I = C \frac{dV_{\text{out}}}{dt} \text{, and } I = \frac{(3.3-V_{\text{out}})}{R}
\]

\[
RC \frac{dV_{\text{out}}}{dt} + V_{\text{out}} = 3.3
\]

**Equation:** \( V_{\text{out}}(t) = 3.3 - 3.3e^{-t/\tau} \)

**General solution of a linear differential equation is** \( V_{\text{out}}(t) = A + Be^{-t/\tau} \).
Since \( V_{\text{out}}(\infty) = 3.3 \text{V}, A = 3.3 \).
Since \( V_{\text{out}}(0) = 0, B = -3.3 \).

\[
\text{SCLK at } 1 \mu s \text{, so the time constant } \tau \text{ is exactly equal to the pulse time.}
\]

\[
V_{\text{out}}(t) = 3.3 - 3.3e^{-t/\tau} \text{ for } 0 \text{ to } 1 \mu s
\]

(5) **Question 9.** Consider three different ADC techniques: flash, sigma delta and successive approximation. Pick the ADC technique that best answers each question. Place an **F** for flash, an **SD** for sigma delta, or an **SA** for successive approximation.

A) Which technique is best for high-precision audio sampling?  
--- **SD**

Audio inputs are sampled with **sigma-delta converters**

B) Which technique is best for low-precision high-frequency sampling?  
--- **F**

Digital scopes use **flash converters**

C) Which technique is used in the TM4C123?  
--- **SA**

Most microcontrollers have **successive approximation** ADC (some have S-D).

D) Which technique has a conversion speed linearly related to the number of bits?  
--- **SA**

You get one bit per clock cycle (guess) in a **successive approximation** ADC.

E) Which technique has a cost exponentially related to the number of bits?  
--- **F**

A 10-bit **flash** has 1024 comparators
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 on these pages. Please don’t turn in any extra sheets.

(10) Question 10. This software measures the 24-bit period on PB6 from rising edge to rising edge using Timer 0A interrupts. Change the software to use PB4 on Timer 1A. Change it to measure from falling edge to falling edge. Cross out parts of the code you wish to delete and insert necessary additions.

```c
uint32_t Period, First, Done;
void PeriodMeasure_Init(void){
    SYSCTL_RCGCTIMER_R |= 0x01; 0x02;
    SYSCTL_RCGCGPIO_R |= 0x02;
    First = 0; Done = 0;
    GPIO_PORTB_DIR_R &= ~0x40 0x10;
    GPIO_PORTB_AFSEL_R |= 0x40 0x10;
    GPIO_PORTB_DEN_R |= 0x40 0x10;
    GPIO_PORTB_PCTL_R = (GPIO_PORTB_PCTL_R&0xF0FFFFFF)+0x07000000;
    TIMER01_CTL_R &= ~0x00000001;
    TIMER01_CFG_R = 0x00000004;
    TIMER01_TAMR_R = 0x00000007;
    TIMER0_CTL_R &= ~0x0000000C;
    TIMER1_CTL_R = (TIMER1_CTL_R&~0x00000008)|0x04;
    //bits 3-2 of TIMER1_CTL_R is TAEVENT = 01
    TIMER01_TAILR_R = 0x0000FFFF;
    TIMER01_TAPR_R = 0xFF;
    TIMER01_IMR_R |= 0x00000004;
    TIMER01_ICR_R = 0x00000004;
    TIMER01_CTL_R |= 0x00000001;
    NVIC_EN0_R = 1<<19; 21;
}
void Timer01A_Handler(void){
    TIMER01_ICR_R = 0x00000004;
    Period = (First - TIMER01_TAR_R)&0x00FFFFFF;
    First = TIMER01_TAR_R;
    Done = 1;
}
```
(15) **Question 11.** Interface this transducer to the ADC. The information is encoded as $V_I$, and it is relative to ground. The transducer output ranges from -0.15 to +0.15V, in other words, $-0.15 \leq V_I \leq +0.15$. Design the analog circuit to create an ADC input range of 0 to +3V. One of the tricks in creating a linear and high-accuracy system is avoiding the extremes of the analog circuits including the ADC. In this system the interesting transducer range is actually only -0.10 to +0.10 V; therefore the interesting signals at the ADC will range from 0.5 to 2.5 V. Include an antialiasing analog filter ($f_c = 1$kHz). Show all resistors, capacitors, and chip numbers. The available power supply voltage is 3.3V. Assume R1 and R2 are already chosen to achieve a reference of 1.5V.

**CANNOT use an instrumentation amp for this circuit because the input is single-ended (not differential)**

Use algebra to derive relationship $V_2 = 10*V_I + 1.5$ (alternate $V_2 = 1.5V - 10*V_I$)

Use reference: $V_2 = 10*V_I + V_{ref}$

Add ground gain: $V_2 = 10*V_I - 10*V_g + 1*V_{ref}$ so the sum of gains is $+1 = 10-10+1$

Choose feedback resistor as a common multiple of 1, 10 (100kΩ)

2 pole Butterworth analog filter, $R = 10$ kΩ

1) Select the cutoff frequency, $f_c$=1 kHz
2) Divide the two capacitors by $2\pi f_c$
   
   $C_{1A} = 141.4\mu F / 2\pi f_c = 141.4\mu F / 2\pi 1000 = 22.5$ nF
   
   $C_{2A} = 70.7\mu F / 2\pi f_c = 11.25$ nF
3) Choose $C_{1B} = 20$ nF and $C_{2B} = 10$ nF
   
   let $C_{1B}, C_{2B}$ be these standard value capacitors, let x be this factor
   
   $C_{1B} = C_{1A} / x, \quad x = 22.5 / 20$
   
   $C_{2B} = C_{2A} / x$
4) Adjust the resistors to maintain the cutoff frequency

   $R = 10k\Omega * x = 11.25$ kΩ (11k makes the LPF cutoff 1023 Hz, close enough)
(10) Question 12. Write an integer function in C that calculates \( \text{output} = \frac{1,000,000}{\text{input}} \), where \( \text{input} \) and \( \text{output} \) are signed 32-bit integers. No floating point allowed. You may assume the \( \text{input} \) is not zero, so overflow cannot occur. However, please implement rounding to the closest integer. In particular test your solution with the following four test cases.

If \( \text{input} \) is +589 then the \( \text{output} \) should be +1698 (close to 1697.79287).
If \( \text{input} \) is +5 then the \( \text{output} \) should be +200,000 (it should be perfect for all exact cases).
If \( \text{input} \) is -7 then the \( \text{output} \) should be -142,857 (close to -142,857.142857).
If \( \text{input} \) is -589 then the \( \text{output} \) should be -1698 (close to -1697.79287).

```c
// add half divisor if positive, subtract half divisor if negative
int32_t function(int32_t input){int32_t output;
if(input<0){
    output = (1000000-input/2)/input;
}else{
    output = (1000000+input/2)/input;
}
return output;
}
```

(5) Question 13. Consider a brushed DC motor. The coil resistance is 10 \( \Omega \) and its inductance is 1 \( \mu \text{H} \). Using circuits, equations and formulas explain the experimental results that steady state 2 A flowed through the motor when a steady state 10 V was applied.

Friction force generates \( \text{emf} \). \( 2V = \frac{(10V-\text{emf})}{10\Omega} \), so \( \text{emf} = -10V \). This \( \text{emf} \) is caused by the mechanical to electrical energy conversion and is not the same as the back \( \text{emf} \) caused by inductance, \( V = L\frac{dI}{dt} \).

(5) Question 14. Consider a simplex synchronous serial interface from master to slave. The master clock is 50% duty cycle 1 MHz \( \text{Clock} \). The master shifts data out on the rising edge of the \( \text{Clock} \). The maximum propagation delay from \( \text{Clock} \) to data output is 200 ns. The slave shifts data in on the falling edge of the \( \text{Clock} \). The slave hold time is 300 ns and the setup time is 100 ns. Complete the timing diagram to scale showing data available and data required timing.

FYI this interface works because DA overlaps DR.