Jonathan W. Valvano

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
B) less EMI emissions
C) it is differential
D) both high and low use energy so it has a larger diameter
E) it can drive less current
F) faster because the capacitance is less

D

It is faster because it can drive more current. It has more EMI emissions
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? -- C

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

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

Tantalum capacitors have a significant equivalent series resistance

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

Classic use of precision (C0G) ceramic capacitors

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

Trick question: software does not need capacitors

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

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**.

1

(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.

C

Resolution is the smallest difference in input that can be detected

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.

G

Precision is the number of different inputs that can be measured

Part c) The input is held constant, and the digital output is recorded multiple times. The standard deviation of these recordings is calculated.

F

Repeatability is a measure of the noise, or variability in measurements

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?

A

Linearity is a measure of the straightness of the output versus input response.

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

C or D

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

B

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).

<pre>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); }}</pre>
	<pre>Add:
	0x000003C4 4902 LDR r1,[pc,#8] ;@0x000003D0
	0x000003C6 6809 LDR r1,[r1,#0x00]
	0x000003C8 4401 ADD r1,r1,r0
	0x000003CA 4A01 LDR r2,[pc,#4] ;@0x000003D0
	0x000003CC 6011 STR r1,[r2,#0x00]
	0x000003CE 4770 BX lr
	0x000003D0 20000000 DCD 0x20000000
	SysTick_Handler:
	0x000004C4 B500 PUSH {lr}
	0x000004C6 2001 MOVS r0,#0x01
	0x000004C8 F7FFFF7C BL Add
	0x000004CC BD00 POP {pc}
	main:
	0x00000510 F7FFFF60 BL Init
	0x00000514 F7FFFF06 BL EnableInterrupts
	0x00000518 E005 B 0x00000526
	0x0000051A F7FFFF0C BL WaitForInterrupt
	0x0000051E F04F30FF MOV r0,#0xFFFFFFFF
	0x00000522 F7FFFF4F BL Add
	0x00000526 E7F8 B 0x0000051A</pre>

(4) Part a) Is there a critical section in the software system shown above?

- **A)** no critical sections
- **B)** yes, with LR
- **C)** yes, access to **`R0`**
- **D)** yes, access to **`Counts`** in **`main`**
- **E)** yes, access to **`Counts`** in **`SysTick_Handler`**
- **F)** yes, access to **`Counts`** in **`Add`**

Answer: A

Interrupts are always triggered during the **`WFI`** instruction

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

Answer: 0x20000000

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?

Answer: 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
- **B)** stored in ROM
- **C)** stored in global RAM
- **D)** the value is fixed and cannot be changed by the function
- **E)** tells the compiler to fetch a new value, and do not optimize
- **F)** promoted to the next high precision

Answer: E

`volatile` turns off the optimization

(2) Part e) What does the **`static`** qualifier for the function **`Add()`** mean?

- **A)** function is public in scope
- **B)** function is stored in ROM
- **C)** run with interrupts disabled
- **D)** the parameters are fixed and cannot be changed
- **E)** function is stored in RAM
- **F)** none of the above

Answer: F

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

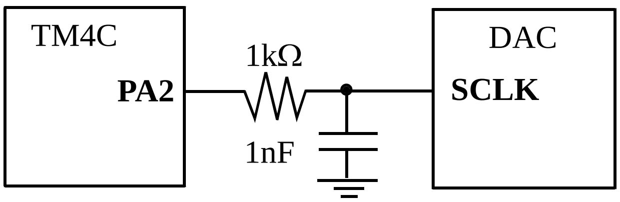
(2) Part f) How does the return from interrupt instruction **`POP {pc}`** change context?

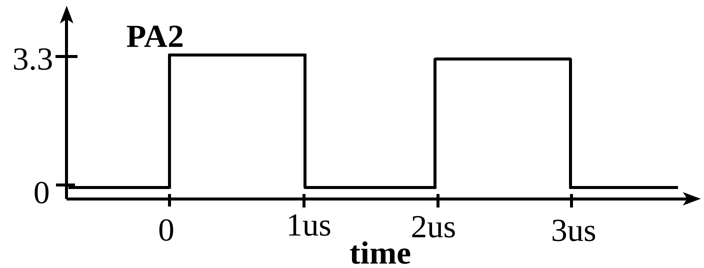
- **A)** gets the PC value from vector table
- **B)** gets the PC value from RAM table
- **C)** moves PC to LR, then pops 8 values
- **D)** pops 0xFFFFFFF9 off stack, then pops 8 more
- **E)** tries to move LR to PC, then pops 8 values
- **F)** pops the return address off stack into PC

The **LR** is 0xFFFFFFF9 at the beginning of the ISR to signify this is an interrupt

Answer: D

(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 $V_{out}(0) = 0$.

At infinite time, the C is an open so, $V_{out}(\infty) = 3.3V$.

$I = C\, dV_{out}/dt$, and $I = (3.3-V_{out})/R$

$RC\, dV_{out}/dt + V_{out} = 3.3$

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

General solution of a linear differential equation is $V_{out}(t) = A + Be^{-t/\tau}$,

Since $V_{out}(\infty) = 3.3V$, $A = 3.3$

Since $V_{out}(0) = 0$, $B = -3.3$

Since $RC(dBe^{-t/\tau}/dt) + Be^{-t/\tau} = 0$, $\tau = RC$

Time constant τ is 1kΩ*1nF = 1µs, so the time constant τ is exactly equal to the pulse time.

$V_{out}(t) = 3.3-3.3e^{-t/\tau}$ for 0 to 1µs

SCLK at 1 µs: $V_{out}(1\mu s) = 3.3-3.3e^{-1}$ $\approx 0.63*3.3V \approx 2V$

(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

Jonathan W. Valvano

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.

```
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;
                                         0xFFF0FFFF   0x00070000;
  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_1, and it is relative to ground. The transducer output ranges from -0.15 to +0.15V, in other words, $-0.15 \leq V_1 \leq +0.15$. 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 = 1kHz). 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 $V_2 = 10*V_1 + 1.5$ (alternate $V_2 = 1.5V-10*V_1$)

Use reference: $V_2 = 10*V_1 + V_{ref}$

Add ground gain: $V_2 = 10*V_1 - 10*Vg + 1*V_{ref}$ 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

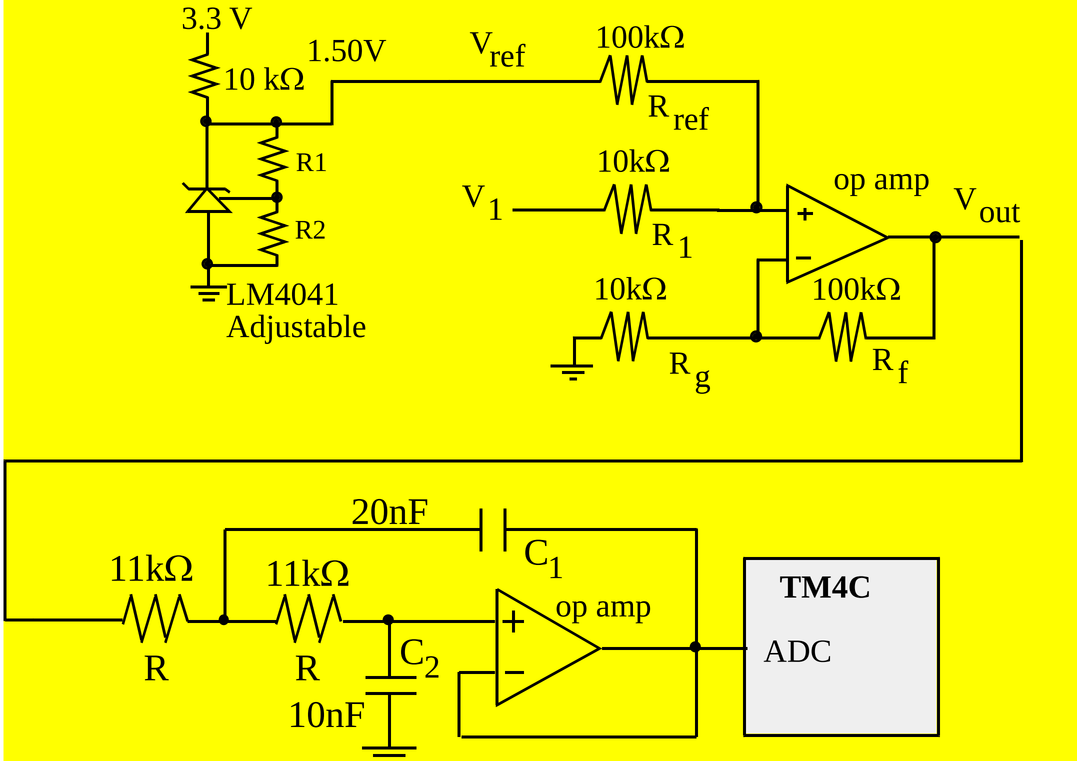
let C_{1B}, C_{2B} be these standard value capacitors, let x be this factor

$C_{1B} = C_{1A}/x$, x = 22.5/20

$C_{2B} = C_{2A}/x$

4) Adjust the resistors to maintain the cutoff frequency

R = 10kΩ•x = 11.25 kΩ (11k makes the LPF cutoff 1023 Hz, close enough)



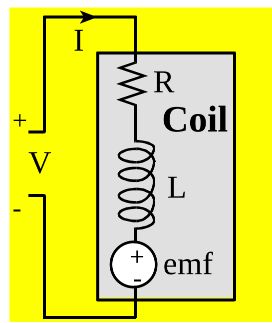
(10) Question 12. Write an integer function in C that calculates **output** = 1,000,000/**input**, where **input** and **output** are signed 32-bit integers. No floating point allowed. You may assume the **input** is not zero, so overflow cannot occur. However, please implement **rounding** to the closest integer. In particular test your solution with the following four test cases.

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

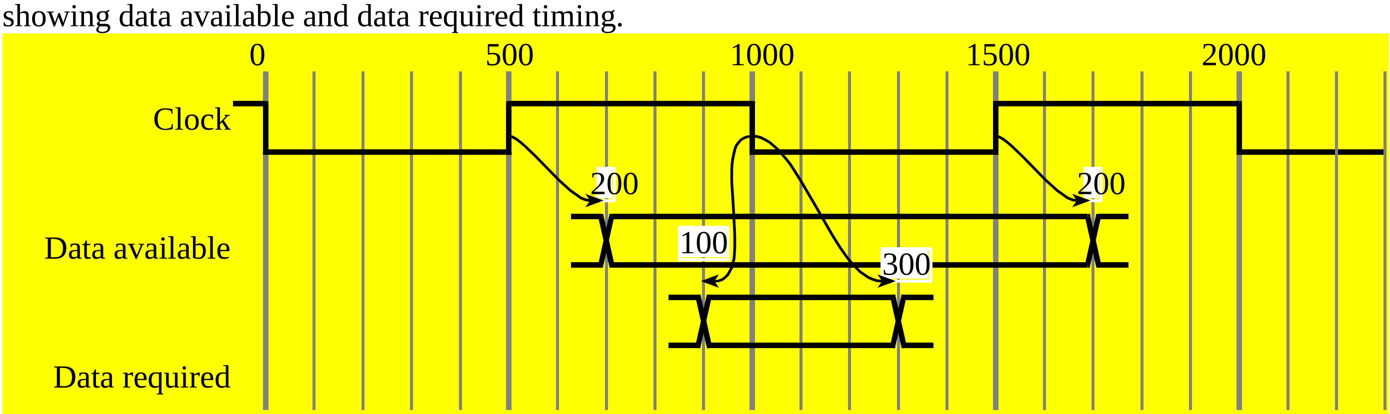
```
// add half divisor if positive, subtract half divisor if negative
int32_t function(int32_t input){int32_t output;
  if(input<0){
    output = (1000000-input/2)/input;
  }else{
    output = (1000000+input/2)/input;
  }
  return output;
}
```

(5) Question 13. Consider a brushed DC motor. The coil resistance is 10 Ω and its inductance is 1 μH. 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 **emf**. 2V = (10V-emf)/10Ω , so emf = -10V.
This **emf** is caused by the mechanical to electrical energy conversion and is not the same as the **back emf** caused by inductance, V = L*dI/dt



(5) Question 14. Consider a simplex synchronous serial interface from master to slave. The master clock is 50% duty cycle 1 MHz *Clock*. The master shifts data out on the rising edge of the *Clock*. The maximum **propagation delay** from *Clock* to data output is 200 ns. The slave shifts data in on the falling edge of the *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