UNIVERSITY OF GLASGOW

Degrees of MEng, BEng, MSc and BSc in Engineering

Embedded Processors 2 (ENG2029)

Friday 13th May 2016
09.30–11.30

The numbers in square brackets in the right-hand margin indicate the marks allotted to the part of the question against which the mark is shown. These marks are for guidance only.

Attempt all questions

An electronic calculator may be used provided that it does not have a facility for either textual storage or display, or for graphical display.

continued overleaf

Q1 The code of Figure Q1A, is executed on a Cortex M0+ microcontroller.

```
#include "mbed.h"
DigitalOut gpo(PTD7);
unsigned int high,low;
unsigned int delay(volatile unsigned int loop)
{ while (loop){
    loop--;
    }
    return loop;
}
int main() {
    high=1200;
    low=3600;
    while (true) {
        gpo = 1;
        delay(high);
        gpo = 0;
       delay(low);
    }
}
```

Figure Q1A

(a) Which line of code is responsible for the initialisation of the I/O port. [2]

(b) The waveform observed at bit 7 of Port D has a period of 300μs when `high` = 1200 and `low` =3600. Sketch the waveform. [6]

(c) Explain the purpose of declaring the variable `loop` to be volatile. What may happen if this variable was not declared volatile? [2]

(d) The parameters high and low are altered and the waveform at pin D7 is now as shown in Figure Q1B. Determine the new values of `high` and `low`. [6]

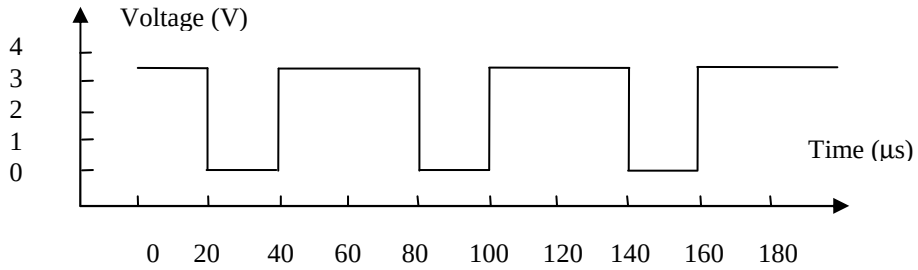

Figure Q1B

(e) The **original** program is to be altered so that a second waveform is generated at pin D6, which should be the inverse of the voltage at pin D7. Describe the additional code necessary. [4]

continued overleaf

Q2 (a) A C program reads from an ADC to measure the voltage from a sensor. The sensor voltage is expected to consist of a constant DC offset, V_{offest}, with a sinusoidal AC ripple of amplitude, V_{ripple}, superimposed on top i.e.

$$V_{sensor} = V_{offset} + V_{ripple} \sin\left(2\pi \frac{t}{T}\right)$$

where t is the time and T is the period of the ripple.

The input voltage range of the ADC is 0 to 3.3V and it produces 12-bit unsigned binary numbers, which are then stored in memory as 16-bit unsigned integers. Part of the storage area is shown below in Figure Q2A as a memory dump. The samples were taken every 1 ms.

Address	Memory Contents
1000	B2 09 FF 09 44 0A 7B 0A
1008	9E 0A AA 0A 9E 0A 7B 0A
1010	44 0A FE 09 B2 09 65 09
1018	20 09 E9 08 C6 08 BA 08
1020	C6 08 E9 08 20 09 65 09
1028	B2 09 FF 09 44 0A 7B 0A

Figure Q2A

(i) What is the magnitude of the DC offset? [4]

(ii) What is the amplitude of the ripple? [4]

(iii) What is the period and frequency of the ripple? [4]

(b) A C program contains two variables `x` and `y`, both of which are floating point numbers stored in the standard IEEE format. The variable `x`=12.0 and `y`=51.0. Figure Q2B is a memory dump of the area used to store these variables. Verify that the variables `x` and `y` are correctly stored in memory. What are their addresses? [8]

Address	Memory Contents
1000	03 FF C0 04 C0 04 DE 5B
1008	E3 01 D1 1E 00 FF 34 00
1010	7B 5B 12 32 00 00 C0 C0
1018	00 00 40 41 00 00 4C 42
1020	00 00 4E 01 6C 59 00 00

Figure Q2B

continued overleaf

Q3 (a) Draw an annotated diagram of a simple ALU, which has two registers A and B and which is connected to memory via an address bus and a data bus. [4]

(b) Explain, with reference to the ALU of part (a), how :

i) data is transferred from memory into register A or B, and how [2]

ii) the result of an arithmetic or logical operation is stored in the accumulator register. [2]

(c) Figure Q3 below is the schematic for a 4-bit ALU. Complete the following table for this 4-bit ALU, where x's represent *don't care* states, and ?'s are to be determined. Explain your result in each case.

K	L	M	N	O	P	Q	A	B	Z	
1	1	1	0	1	0	0	1101	0111	????	[3]
0	0	1	0	1	0	0	????	1001	1111	[3]
?	?	?	?	?	?	?	xxxx	1110	1111	[3]
x	x	x	x	x	1	1	0101	1011	????	[3]

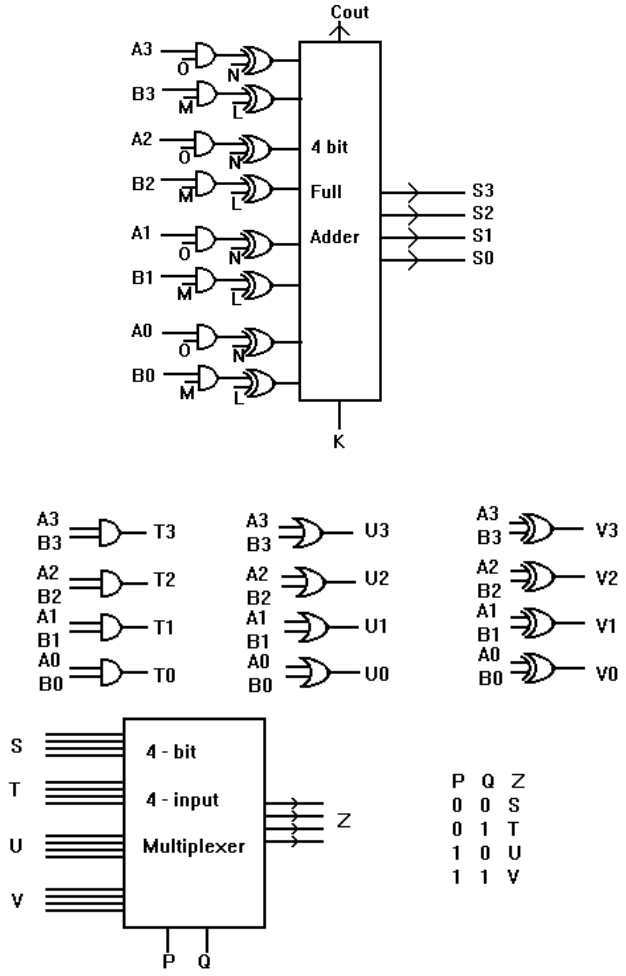

Figure Q3: A and B are 4-bit inputs. Z is a 4-bit output.
K, L, M, N, O, P and Q are control lines.

continued overleaf

Q4 The program listing, Figure Q4, shows a program which is executed on a *Freescale Freedom Board*.

(a) (i) In the *mbed* programming environment what is meant by a *Ticker*? [2]

(ii) Explain the operation of the following line in the program:

```
TimerInt.attach(&SignalGenerator,0.005);
```

and hence sketch the output signal at pin PTD7. [4]

(iii) Sketch the output signal at pin PTE30. [2]

```
#include "mbed.h"

Ticker TimerInt;
DigitalOut gpo(PTD7);
Serial async_port(PTA2,PTA1);
AnalogOut Aout(PTE30);
float x;
volatile unsigned int i,j,signal;
unsigned int store[64];
unsigned char msb,lsb;

void SignalGenerator(){
    gpo=j&1;
    signal=store[j];
    Aout.write_u16(signal);
    signal=(signal>>4);
    lsb=signal & 0x00ff;
    msb=(signal >>8);
    async_port.putc(msb);
    async_port.putc(lsb);
    j++;
    if(j==64) j=0;
}

int main() {
    for (i=0; i<64; i++) {
        x=16*2047.0*(1+sin(2*3.142*i/64));
        store[i]=x;
    }
    async_port.baud(9600);
    TimerInt.attach(&SignalGenerator,0.005);
    j=0;
    while(1) {
    }
}
```

Figure Q4

(b) To check that the program is operating correctly, the values in the array `store` are split into bytes inside the routine `SignalGenerator`. These are then transmitted to a second microcontroller. When the value which has been split in this way is 63008, sketch the waveform which would subsequently be observed on the asynchronous serial output pin A2. How long does it take to transmit these two bytes? [8]

(c) What would need to be changed in the program if the DAC had to be updated every 1ms? [4]

continued overleaf

Q5 (a) (i) ARM Cortex processors use *memory mapped I/O*. Explain what is meant by this phrase. [2]

(ii) Describe the purpose of the following registers which determine the mode of operation of I/O on a Cortex processor:

- Port Data Direction Register
- Pin Control Register and
- System Gating Control Register. [3]

(b) The code of Figure Q5 is executed on Freescale Freedom Board. Assume that the function `delayms(int n)` creates a delay of `n` ms.

```
#include <MKL25Z4.H>

int main (void) {
    void delayms(int n);

    SIM->SCGC5 |= 0x400;
    PORTB->PCR[19] = 0x100;
    PTB->PDDR |= 0x80000;

    while (1) {
        PTB->PCOR = 0x80000;
        delayms(500);
        PTB->PSOR = 0x80000;
        delayms(500);
        PTB->PTOR = 0x80000;
        delayms(500);
        PTB->PTOR = 0x80000;
        delayms(500);
    }
}
```

Figure Q5

(i) Describe the actions carried out by writing to the registers `PSOR`, `PCOR` and `PTOR`. [3]

(ii) Determine which pin is being accessed by this code and sketch the voltage which would be observed on this pin. [3]

(iii) What changes would be necessary in this program so that the output would be produced on port B pin 1? [4]

(c) (i) Describe the SysTick timer which is found in all ARM Cortex microcontrollers. [2]

(ii) A SysTick timer has been set up so that it creates interrupts. If the timer has been loaded with its maximum value and the processor system clock is 20.97MHz, calculate the time between interrupts. [3]

End of question paper