ESS: Exercise Set 5

Peripherals

Question 1:

Two devices are communicating using asynchronous serial UART. The baudrate is 57600 bps, with 1 start bit, 8 data bits and 1 stop bit. Each device is run from its own, independent clock (oscillator).

(a) What is the throughput of the serial link (maximum number of data bits per second)?

> Solution:
>
> To send a byte (8 data bits), it is padded with a start and stop bit. This means that only 8 out of 10 bits are actually useful data bits. Hence the data throughput is $0.8 \times 57600 = 46080$bps.

(b) What is the maximum error that can be tolerated between the two clocks before timing errors will occur? (hint: we start timing at the start bit and need to keep clocks synchronized until the stop bit. In a noisy environment, there will be jitter on transitions, so we need to sample the last bit within ±0.25 bits of the true position.)

> Solution:
>
> We start timing as soon as we receive the leading edge of the start bit. We need to be accurate to within 0.25 bits of the final bit position. This means that we need to be able to time 9.5 bits within 0.25 bits. Hence the maximum clock error is $\frac{\pm 0.25}{9.5} 57600Hz = \pm 1515Hz$. The total tolerance on the clocks is thus $\pm \frac{1515}{57600} = 2.63\%$

(c) What is the tolerance we need on each device's clock?

> Solution:
>
> The total tolerance is shared between the two ends, assuming both are equal, then we need a clock with an accuracy of 1.31%.

(d) To generate the baudrate, we can use the following oscillators, which each contribute the following cost to the BOM:

- 64 MHz, with a tolerance of ±50 ppm (parts per million), a unit cost of $2.30 and a supply current of 1 mA
- 16 MHz, with a tolerance of ±2% and a unit cost of $0.20 and a supply current of 0.1 mA
- 8 MHz, with a tolerance of ±4% and a unit cost of $0.00 (internal RC) and a supply current of 0.01 mA

Which oscillator would be suitable for a industrial control system? Which oscillator would be suitable for a mass-produced toy?

Solution:
The 64 MHz oscillator would be best for an industrial control system, as the consequence of an error could be significant. The cheapest oscillator, the 8 MHz unit, does not meet the tolerance bounds, hence, for a low cost toy, the 16 MHz oscillator could be used.

(e) What strategies can you think of to minimize this problem?

Solution:
One solution is to use auto-bauding where a known header or preamble, such as 0xAA is sent before a long packet. The receiver can use the bit timings to compensate its own oscillator and thus tolerate far greater deviations in clock drift. Another solution is to use a synchronous protocol, where the clock is sent as well as the data, this can be done either using an additional line or by encoding the clock into the signal at the cost of halving the effective bit rate.

Question 2:
A 12 bit DAC has a reference voltage of 3.3V. What digital word would result in a voltage of 1.32V? What is the relative error?

Solution:
A 12 bit DAC has 4096 unique output levels, including 0V. The reference voltage, 3.3V, corresponds to the digital word 0xFFF (4095). Thus the voltage per step is $\frac{3.3}{4095}V = 0.805mV$. 1.32V corresponds to the number 1638 which is 0x666.

Question 3:
A 4 bit DAC can be used in conjunction with a comparator to digitize an analog voltage. Design an algorithm that the controller could use to find the digitized value.

Solution:
The simplest algorithm is to count up from 0 and indicate when the bit toggles. This however is extremely inefficient, as the number of steps required is 2^n for an n bit ADC. A better technique is a divide and conquer approach, starting from the most significant bit and working down. This only takes n steps to approximate the analog value.

Question 4:
A temperature sensor has an output from 0V to 3V, where 1V corresponds to 0°C

and 2V corresponds to 100°C. This signal is digitized with an ADC, with a full-scale range from 0V to 3V.

(a) Using an 8-bit ADC, what is the resolution of a voltage that can be measured?

> Solution:
> Resolution is $\frac{3}{255} = 0.011764706$V per step.

(b) Using an 8-bit ADC, what is the resolution of the temperature that can be measured?

> Solution:
> A range of 100°C corresponds to a voltage swing of 1V. 1V equates to 85 individual voltage steps. Hence, the temperature resolution that could be sensed is 1.17 °C per bit.

(c) To achieve a resolution of 0.1°C, how many bits should the ADC have as a minimum?

> Solution:
> This means that over a 1V range, we would need to have 1000 individual voltage levels. We are spanning a 3V range, so in total, we would need 3000 voltage levels. The next best ADC that satisfies this would be a 12 bit ADC which provides 4096 levels over a 3V range. An alternative would be to amplify the input voltage to span the full range.

Question 5:

A timer has a period of 1000 counts. It has a 4 channel PWM module. Draw the output waveforms for:

- Timer counter
- Ch1 with a compare value of 250

> Solution:
> On for 25% of time, off for 75% of time.

- Ch2 with a compare value of 600

> Solution:
> On for 60% of time, off for 40% of time.

- Ch3 with a compare value of 10

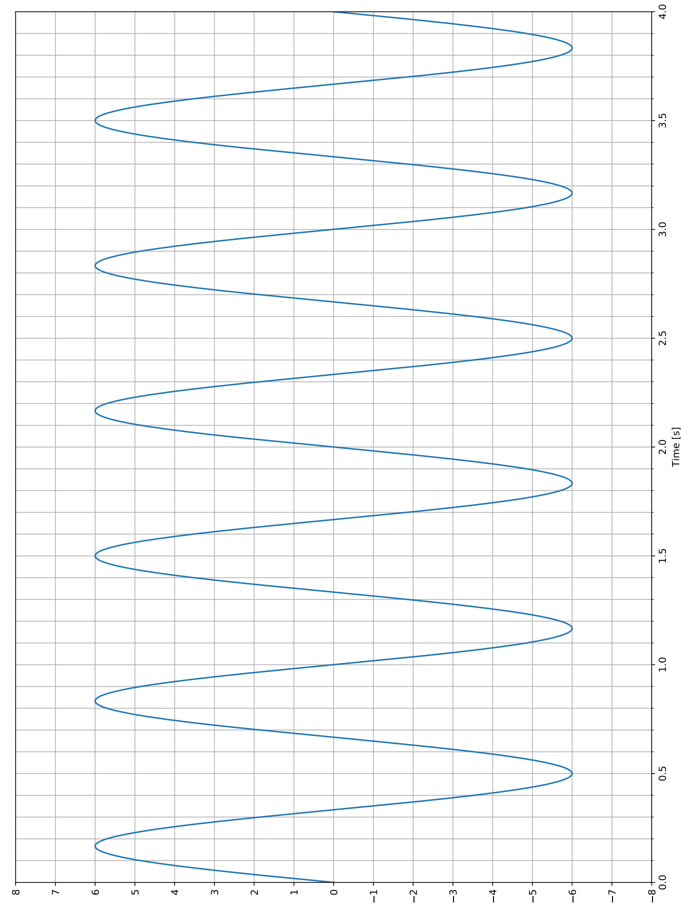
Solution:
On for 1% of time, off for 99% of time.

- Ch4 with a compare value of 2000

Solution:
On for 100% of time (compare value never reached).

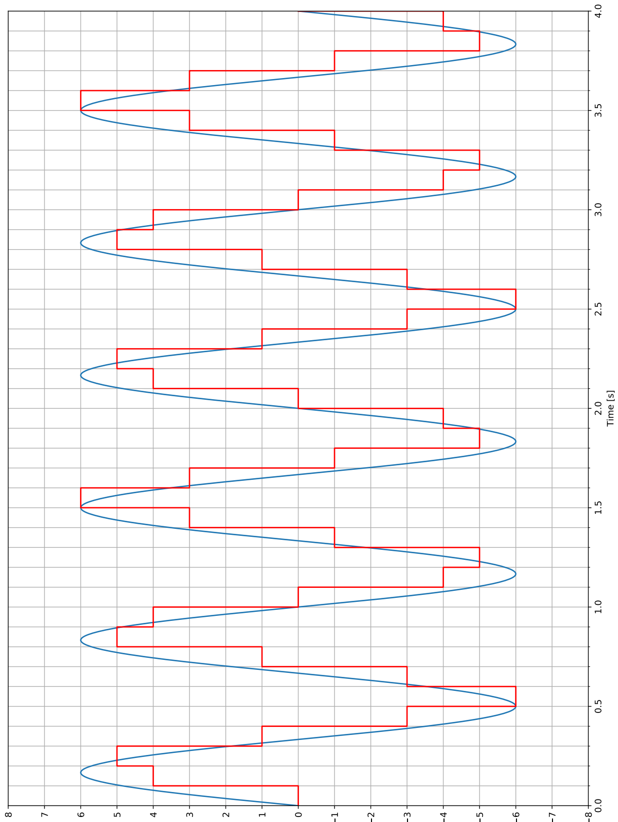
Question 6:

The figure shows a sinusoidal waveform that is to be digitized by a 16 level ADC. Show the reconstructed waveform for sampling rates of 10 Hz, 5 Hz, 2 Hz and 1 Hz.



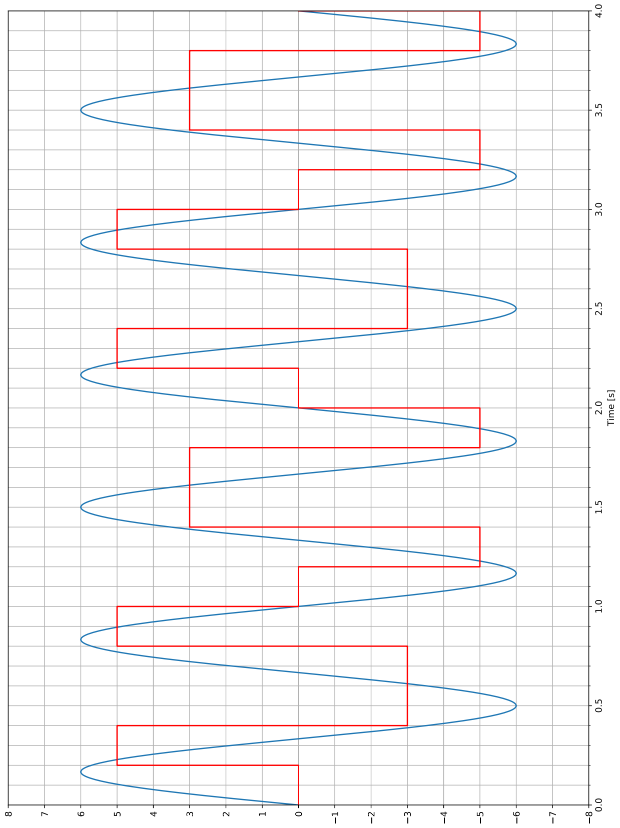
Solution:

10 Hz sampling rate.



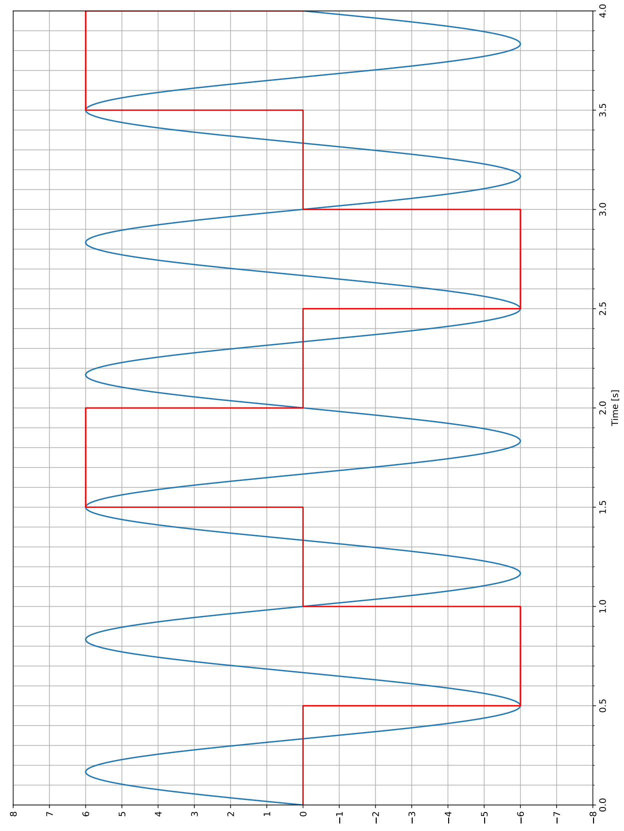
Solution:

5 Hz sampling rate.



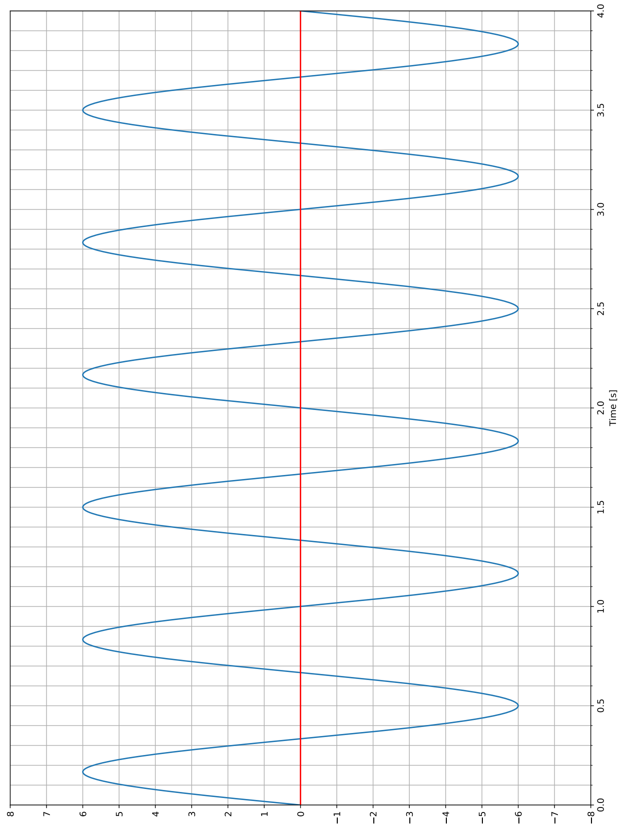
Solution:

2 Hz sampling rate.



Solution:

1 Hz sampling rate.


Time [s]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
8
7
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8