Solutions : DSP software tech test

Task 1: Create a script to read in the testData.txt into your preferred language (do not use Matlab/Octave/R).

- C code placed under DSP software developer test\C_Code\dspswtest\src\task1.c
- Please refer HelpDoc.pdf to navigate and run this code.

Task 2: Estimate DC offset D_m for all elements.

- C code placed under DSP software developer test\C_Code\dspswtest\src\task2.c
- Please refer HelpDoc.pdf to navigate and run this code.
- Estimated DC offset D_m(for all 8 elements) is captured below.

```
MINGW64:/c/Users/Lenovo/eclipse-workspace/make_test_try/Debug    MINGW64:/c/Users/Lenovo/e
$ ./make_test_try.exe task2
********************** DC Offset Estimation for window[0] **********************
Antenna 0 DC Offset: 0.248149
Antenna 1 DC Offset: 0.621656
Antenna 2 DC Offset: 0.458180
Antenna 3 DC Offset: 0.567822
Antenna 4 DC Offset: 0.752802
Antenna 5 DC Offset: 0.317122
Antenna 6 DC Offset: 0.434838
Antenna 7 DC Offset: 0.470183
```

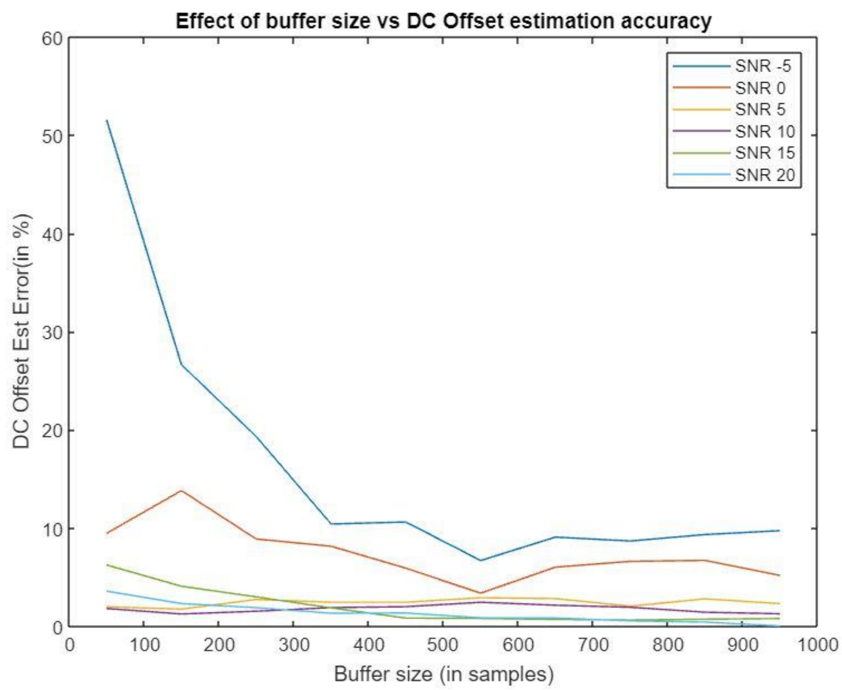
Task2, Question 1: How does buffer size affect estimation accuracy?

- Buffer size directly affects the accuracy of the DC offset estimation. Here's how buffer size affects estimation accuracy:
- A smaller buffer, let's say around 100-150 data points, has its advantages and disadvantages. On the positive side, it offers lower latency, meaning it processes data more quickly, and it's also more memory-efficient. However, there are limitations. Since it uses fewer data points for estimation, the accuracy of its estimates may be somewhat compromised. Additionally, it's better at capturing short-term variations in the signal. But it's a good choice when we need speedy estimations and when the signal we're dealing which has low noise, typically with a Signal-to-Noise Ratio (SNR) above 5dB(as shown in below simulated plot).

- Larger buffer size gives better accuracy by capturing more data points for estimation.Averaging over a larger buffer can help smooth out short-term variations in the received signal, providing a more stable estimate. However, it comes at the cost of higher latency and increased memory usage. But if accuracy and stability are critical and we can tolerate slightly higher latency, a larger buffer size might be appropriate and also when the signal we're dealing with has large noise variations . It's because when estimating the DC offset, these variations can be mistaken as part of the offset, leading to a biased estimate(higher or lower than the actual DC offset due to noise). This is particularly problematic when the noise level is high(below 0dB of SNR as depicted in below plot) compared to the amplitude of the DC offset.

Ultimately, the optimal buffer size depends on the balance between accuracy, latency, memory usage, and the specific requirements of application. Below matlab simulation helps to experiment with buffer sizes and evaluate the trade-offs in terms of estimation accuracy and buffer size. Below plot is generated by considering received signals modeled as:

$$y_m(n) = e^{j\frac{2\pi f n}{fs}} + D_m + P_m(n),$$



Task2, Question 2: List a few cons and pros behind buffer size selection?

Chosen a buffer size of 400 samples which gives decent accuracy in estimated dc offset value for a good range of low & high SNR regions (as simulated in last plot).

Pros:
- Smaller buffers process data more quickly, leading to reduced delay in processing as it handles fewer data points..
- Smaller buffers consume less memory. From a coding perspective, the buffer can be declared on the stack itself, as a small buffer size like this won't lead to a stack overflow issue

Cons:
- Uses fewer data points for estimation, potentially resulting in less accurate results.

- They are better at capturing short-term variations in the signal but may miss long-term trends.
- Smaller buffers are more susceptible to the impact of high noise on the data.

Task2, Question 3: Is it possible to average DC estimate over antenna elements? If no why not?

From the given receiver model equation it's a bit unclear if both Tx & rx are introducing DC offset. Because :

- If the transmitter adds a DC offset(leakage from the transmitter to the receiver path) to the transmitted signal but the receivers do not introduce any additional DC offsets, it is possible to average the DC offset estimates across antenna elements. This is because the added DC offset is consistent across all elements and is solely a characteristic of the transmitted signal.Since the added DC offset is consistent and is not affected by the receivers, the estimated DC offsets from different antenna elements should have similar characteristics. This makes it possible to average the estimates to obtain a more accurate estimation of the true DC offset.

- If each receiver adds its own DC offset to the received signal, it becomes much more challenging to accurately average the DC offset estimates across antenna elements. This is because averaging DC offset estimates across antenna elements assumes that the DC offset is consistent and primarily due to the characteristics of the antenna elements themselves. However, if the receivers are adding their own DC offsets, the resulting offsets will likely vary significantly between different antennas due to differences in receiver circuitry, amplification,LO Leakage, Imbalanced Mixers and other factors.This can lead to inaccurate averaging and incorrect estimation of the true DC offset.

Note : Looking at the variation in estimated DC offset(in below screenshot from *TASK2*) over different antennas signifies that the receiver adds its own DC offset to the received signal. If we perform averaging DC estimates over an antenna it can lead to incorrect estimation . So we cannot perform averaging over different antennas.

Task 3: With a given buffer size, propose a method to improve estimation accuracy on DC offset. Implement your idea in language selected in Task 1.

- DC offset estimation involves averaging the signal over a period to eliminate variations caused by noise. However, if the noise is significant, it can still affect the accuracy of the estimation. Noise can lead to biases in the estimated DC offset, causing it to deviate from the true value.
- **Improve estimation accuracy on DC offset:** Apply noise reduction techniques with moving average filter.To apply noise reduction with a moving average filter, slide the filter window through the signal. At each position, calculate the average of the set of adjacent data points within the window. This average value becomes the new value for that position.The moving average filter has the effect of smoothing out variations in the data,

including noise. As the window slides through the signal, it reduces the impact of random fluctuations and highlights the underlying trends or significant features.

- C code placed under DSP software developer test\C_Code\dspswtest\src\task3.c

Task 4 Question 1: Propose a computational efficient method to estimate frequency f?

- The two complex sample method is computationally efficient as it doesn't require a full FFT computation while still providing a reasonable estimate of the signal's frequency. However, it's worth noting that this approach can be susceptible to inaccuracies due to noise and DC offset.
- To enhance the accuracy of frequency estimation, particularly in noisy scenarios, we can employ moving average filtering. Additionally, removing the DC offset, as demonstrated in the response to Task 4 Question 2 (with detailed analysis and plots), can further refine the estimation process.

Note : supporting Script is placed inside folder script->Task4Script.m

Task 4 Question 2: Can you use two complex sample to estimate the frequency?

Yes.

Steps to use two complex sample to estimate the frequency

- Multiply the current sample (y(n)) with the complex conjugate of the previous sample (y(n-1)) to obtain x(n). This demodulation process helps isolate the phase information of the signal.

  $x(n) = y(n) * conj(y(n - 1));$
- Calculate the phase of x(n) using the tan inverse. This phase represents the phase difference between the current and previous samples.

  $phase(x(n)) = tan^{-1}(imag(x(n))/real(x(n)))$
- Frequency Estimation: With the known sampling rate (f_s), we can estimate the frequency (f_{est}) of the signal.

  $f_{est} = f_s * phase(x(n))/2\pi;$

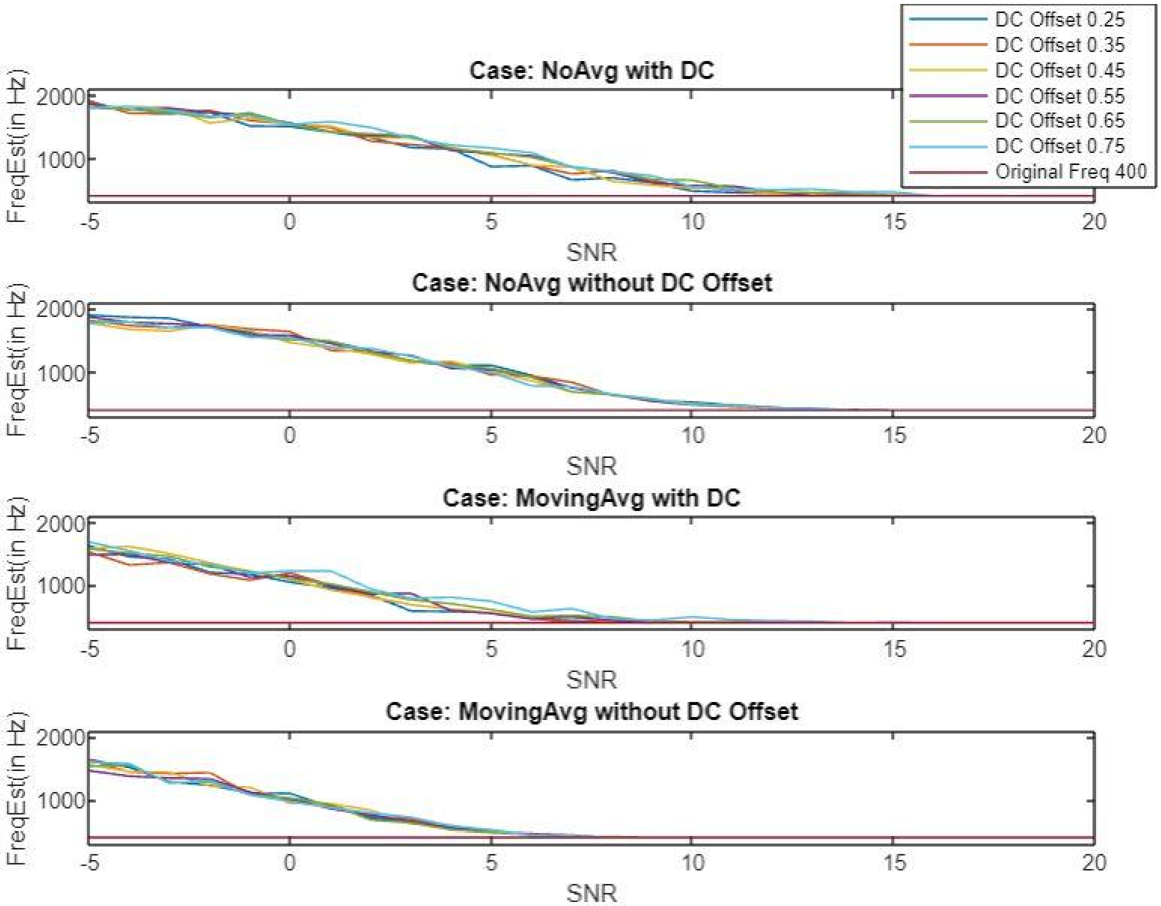
But the above technique has few restrictions on requirement of signal characteristics, where Noise and DC offset can introduce errors in frequency estimation when using two complex samples. Noise can lead to variations in the amplitude of the complex samples. This can affect the accuracy of the frequency estimate and DC offset can cause a shift in the baseline of the complex samples, which may result in a biased frequency estimate.

Here I simulated received signal model $y_m(n) = e^{j\frac{2\pi f n}{f_s}} + D_m + P_m(n),$ to see the impact of different SNR & DC offset on frequency estimation (f_s = 4Khz , f = 400Hz)

Note : supporting script placed inside folder script->Task4_Q2.m

In below plot, different cases is to show how we can improve estimation accuracy by

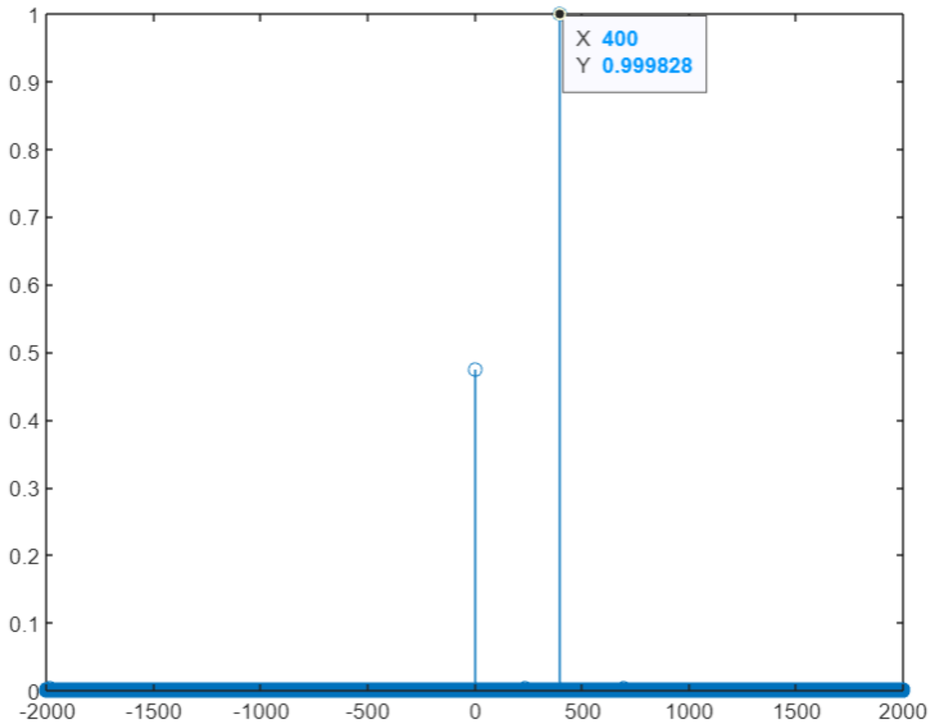
- Applying noise reduction techniques with moving average filter.
- Estimate and compensate for DC offset.




```
>> Task4Script
Ant[1] - Original DC Offset: 0.2503, Estimated DC Offset: 0.2503 : Signal Frequency: 400.00 Hz, FreqEstimation: 494.48 Hz , After Noise smoothning FreqEstimation: 399.99 H
Ant[2] - Original DC Offset: 0.6001, Estimated DC Offset: 0.6001 : Signal Frequency: 400.00 Hz, FreqEstimation: 561.40 Hz , After Noise smoothning FreqEstimation: 399.99 H
Ant[3] - Original DC Offset: 0.4582, Estimated DC Offset: 0.4582 : Signal Frequency: 400.00 Hz, FreqEstimation: 518.04 Hz , After Noise smoothning FreqEstimation: 399.99 H
Ant[4] - Original DC Offset: 0.5677, Estimated DC Offset: 0.5677 : Signal Frequency: 400.00 Hz, FreqEstimation: 546.48 Hz , After Noise smoothning FreqEstimation: 399.99 H
Ant[5] - Original DC Offset: 0.7541, Estimated DC Offset: 0.7541 : Signal Frequency: 400.00 Hz, FreqEstimation: 634.92 Hz , After Noise smoothning FreqEstimation: 399.99 H
Ant[6] - Original DC Offset: 0.3436, Estimated DC Offset: 0.3436 : Signal Frequency: 400.00 Hz, FreqEstimation: 502.04 Hz , After Noise smoothning FreqEstimation: 399.99 H
Ant[7] - Original DC Offset: 0.4319, Estimated DC Offset: 0.4319 : Signal Frequency: 400.00 Hz, FreqEstimation: 514.24 Hz , After Noise smoothning FreqEstimation: 399.99 H
Ant[8] - Original DC Offset: 0.4757, Estimated DC Offset: 0.4757 : Signal Frequency: 400.00 Hz, FreqEstimation: 523.76 Hz , After Noise smoothning FreqEstimation: 399.99 H
```

Task 4 Question 3: What is the frequency on recorded signal?

Answer : f = **400** Hz **,** below is the plot of frequency of recorded signal



X 400
Y 0.999828
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-2000
-1500
-1000
-500
0
500
1000
1500
2000