深 圳 大 学 实 验 报 告

课程名称：　　　　　随机信号处理

实验项目名称：　　Sampling and estimating spectrum

学院：　　　　　　电子与信息工程学院

专业：　　　　　　电子信息工程

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班级：**22 文华班**

实验时间：**2024 年 5 月 20 日——2024 年 6 月 19 日**

实验报告提交时间：**2024 年 6 月 19 日**

教务处制

Description of format:

- Use Times New Roman, 12 pt, single column, single line spacing.
- When inserting figures and tables, title of the figures and tables must be included.
- Do not change '1、Purposes of the experiment' and '2、Design task and detail requirement'.

1、Purposes of the experiment

1) learn the periodogram and Correlogram method to estimate power spectrum.
2) Use Matlab to sample a chirp signal and learn the matched filter.
3) Analyze the results and draw reasonable conclusions

2、Design task and detail requirement

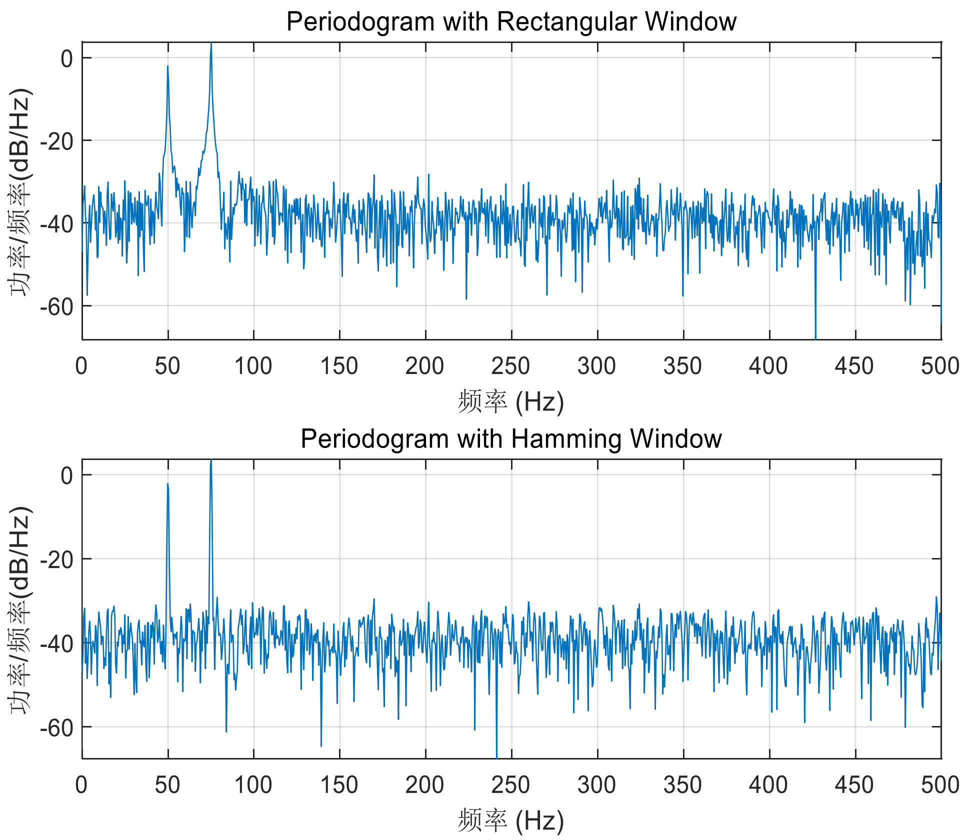
See 'Appendix 1 – Task and requirement for experimental report 3.doc'.

3、The result and Analysis

- **Part 1: Basic 1 (40 points)**

You should submit your codes that can generate the figures in 3). The codes should be runnable!

1) Plot the Periodogram with different window (rectangular and hamming), and compare the results, describe the differences.



Basic1 periodogram with different window

Result analysis:

Formula: $\omega = 2\pi f$

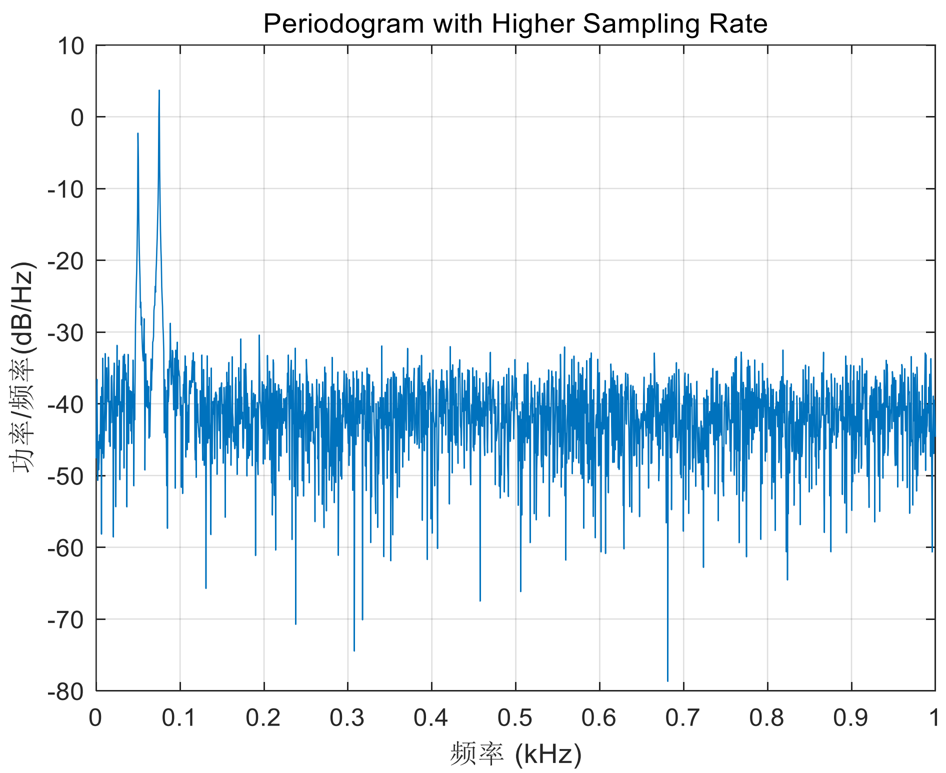
Maximum values appear in f =50Hz and f =75Hz, corresponding to ω=100π and ω=150π

Hamming window is able to reduce side lobe, especially in f =50Hz and f =75Hz

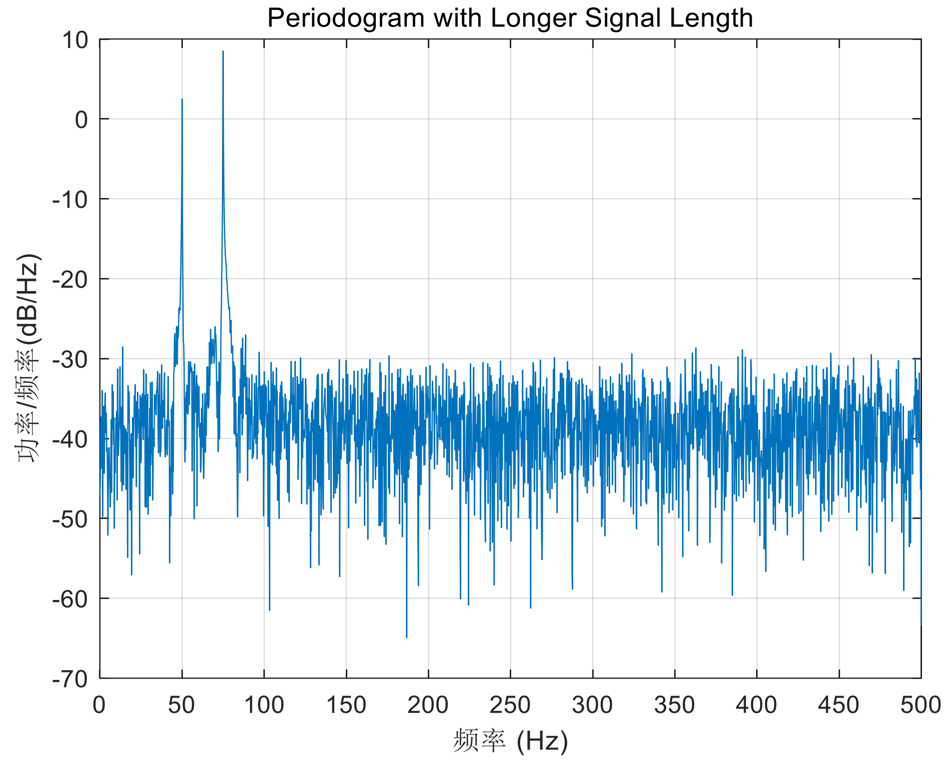
Comparison and Description:

- Rectangular window typically results in higher side lobes, which can obscure nearby frequency components.
- Hamming window reduces the side lobe levels, providing a clearer view of the main lobes of the frequency components.

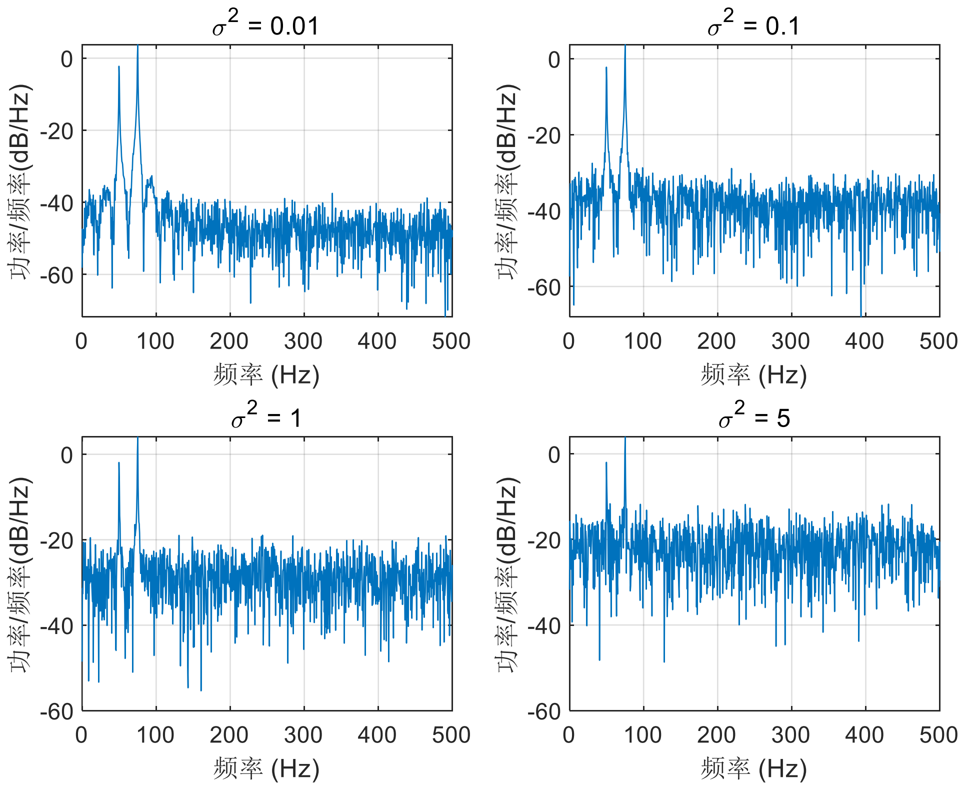
2) Change the sampling rate, signal length, FFT length and the value of σ^2, use the Periodogram to do the spectrum estimation. Show your results (you can use figures and/or figures), and give analysis.



Periodogram with Higher Sampling Rate and rectangular window



Periodogram with longer signal length and rectangular window



Periodogram with different variance and rectangular window

Analyzing the Effects:

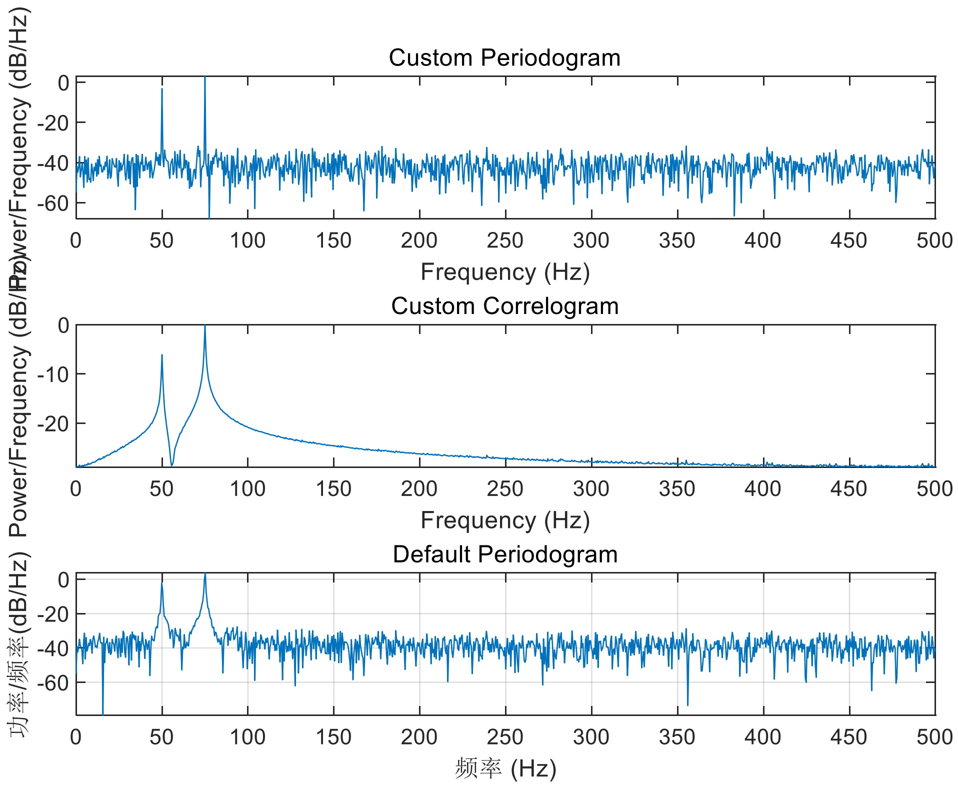
- **Sampling Rate:** Higher sampling rates provide better resolution in the

frequency domain but require more computational resources.
- **Signal Length:** Longer signals result in better frequency resolution but increase computation time.
- **σ^2:** Increasing the noise power makes it harder to distinguish the signal components from the noise.

Summary of Analysis:

- **Sampling Rate:** Increasing the sampling rate improves frequency resolution but may not significantly change the periodogram's overall shape.
- **Signal Length:** Increasing the signal length provides better frequency resolution, reducing spectral leakage.
- **Noise Power (σ^2)**: Lower noise power (σ^2) makes the signal components more visible. Higher noise power can obscure the signal components, making it difficult to distinguish them.

3) plot the figures/tables in 2) using your own Periodogram and Correlogram again, and show the comparison between your own Periodogram and Correlogram function and the default Periodogram function used in 2)



Summary of Comparison

1. **Custom Periodogram vs. Default Periodogram:**
   - The custom periodogram should closely match the default periodogram in shape and magnitude, demonstrating the accuracy of the custom implementation.

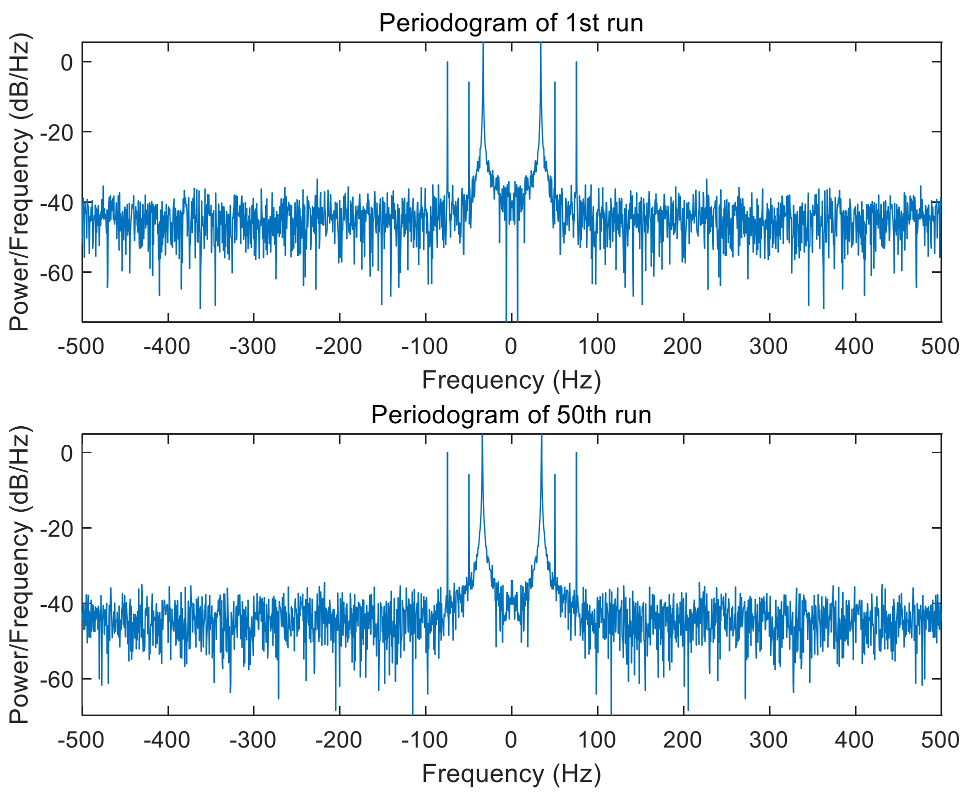
- The custom periodogram reduces the side lobe levels, providing a clearer view of the main lobes of the frequency components.

2. **Custom Correlogram vs. Default Periodogram:**
   - The custom correlogram should also reveal the signal's spectral components but might show slight differences due to the method of computation (autocorrelation vs. direct Fourier transform).
   - At the peak, the custom correlogram can be well expressed, and it can filter out a lot of noise, making the curve more gentle and intuitive, and good robustness.

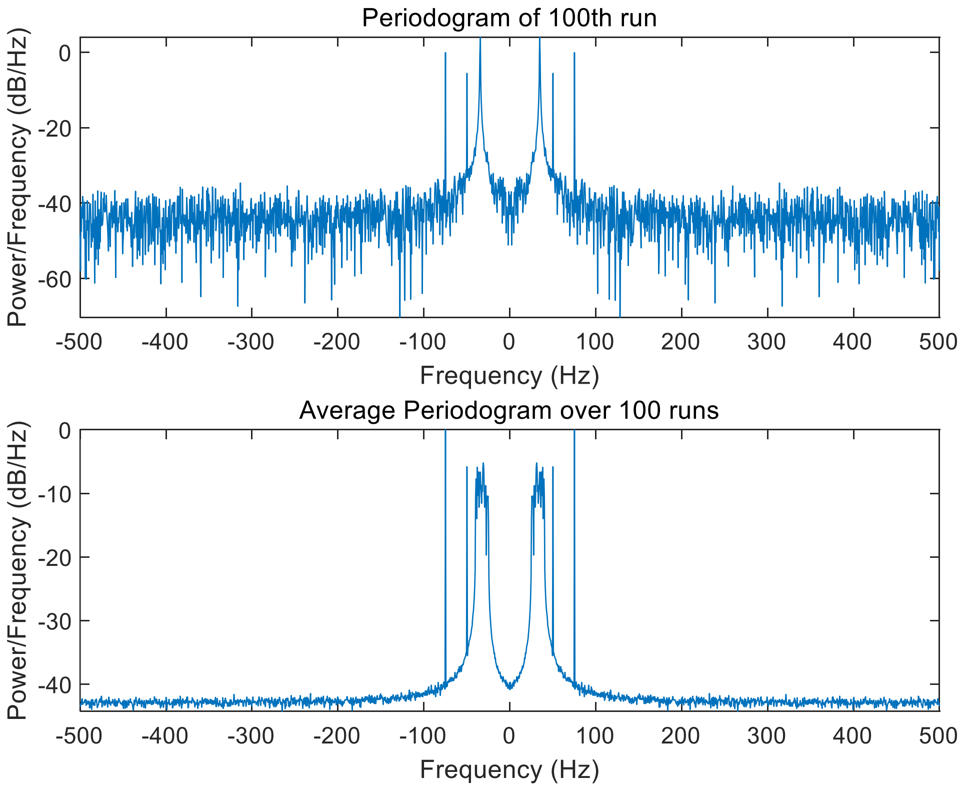
- **Part 2: Basic 2 (40 points)**

You should submit your codes that can generate the figures in 1). The codes should be runnable!

1) Plot the periodogram of the 1st, 50nd, 100nd run and the power spectrum. (there are totally four figures, show your figures here only, analysis can be given in 2) below)

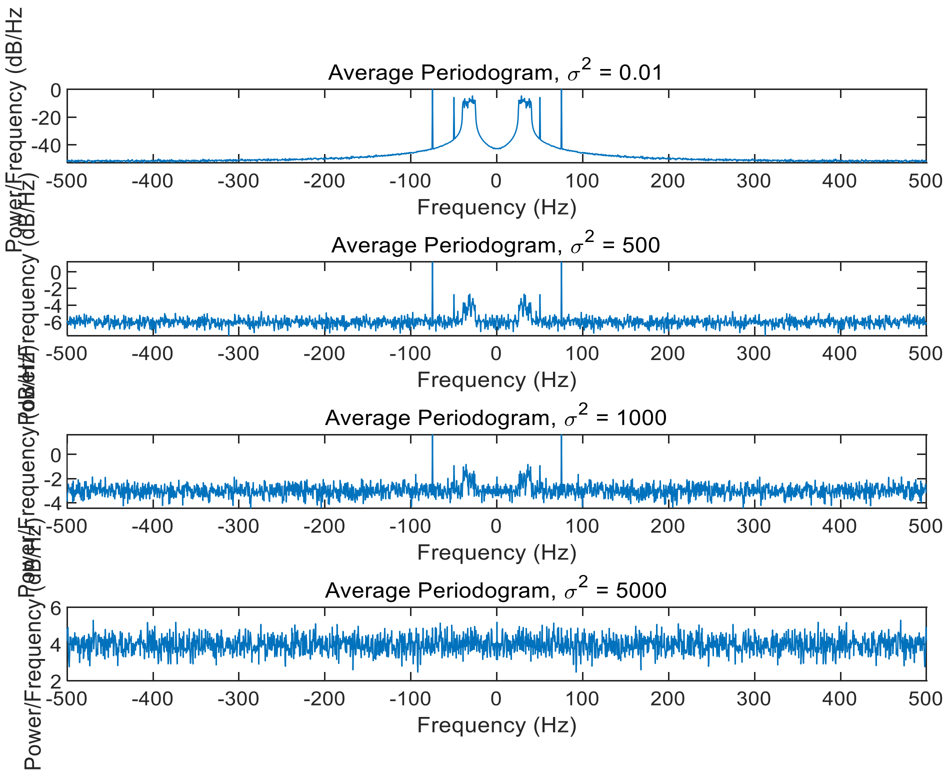


Periodogram with 1th and 50th run



Periodogram with 100th run and average periodogram

2) Show the power spectrum result for different σ^2 and provide analysis.



Average periodogram with different σ^2

Result analysis:
Formula: $\omega = 2\pi f$
Maximum values appear in f =50Hz and f =75Hz, corresponding to ω=100π and ω=150π
However, when we observe the periodogram of the 1st, 50nd, 100nd run, we can see that there will be a random peak between 25 and 40Hz.
If we take the average, these peaks will become a smooth oscillation process, we can not consider it, and will not be affected by interference.

By observing average periodogram with different $\boldsymbol{\sigma^2}$, We can find that when the variance is small enough, noise interference will not affect our observation of the peak value. When the variance reaches 1000, we will find that the peak value at 50Hz can no longer be observed, and when the variance reaches 5000Hz, the peak value at 75Hz can no longer be observed.

- **Part 3: Advance (40 points)**

1) You are required to submit your code, and your code should directly give all the tables or figures in 1.2).

1.1) Plot your system flow chart. You can provide necessary explanations.

```
Initialize Environment
- Clear workspace
- Set random seed
            |
            v
   Set Parameters
- Chirp signal params
- Full signal params
            |
            v
Define Testing Params
- Number of tests
- SNR range
            |
            v
Initialize Result Storage
- MSE array
- Accuracy array
            |
            v
Loop Over SNR Values
For each SNR value:
            |
            v
```

Calculate Noise Power
|
v
Perform Tests (numTests)
For each test:
|
v
Generate Random Insertion Point
|
v
Generate Noise and Insert Signal
|
v
Apply Matched Filtering
|
v
Estimate End Time
|
v
Calculate MSE and Accuracy
|
v
Store Results
- MSE
- Accuracy
|
v
Display and Plot Results

Explanation of Flow Chart

1. **Initialize Environment**: Clears any previous data and sets the random seed to ensure repeatability of the results.
2. **Set Parameters**: Defines the parameters for the chirp signal and the full signal.
3. **Testing Parameters**: Sets the number of tests to be performed and defines the range of SNR values to be tested.
4. **Initialize Result Storage**: Creates arrays to store the results of the MSE and accuracy for each SNR value.
5. **Loop Over SNR Values**: For each SNR value, the noise power is calculated, and multiple tests are performed.
6. **Generate Random Insertion Point**: For each test, a random start point is selected where the chirp signal will be inserted into the noise.
7. **Generate Noise and Insert Signal**: Noise is generated and scaled, and the chirp signal is inserted at the random start point.
8. **Apply Matched Filtering**: A matched filter is applied to the noisy signal to

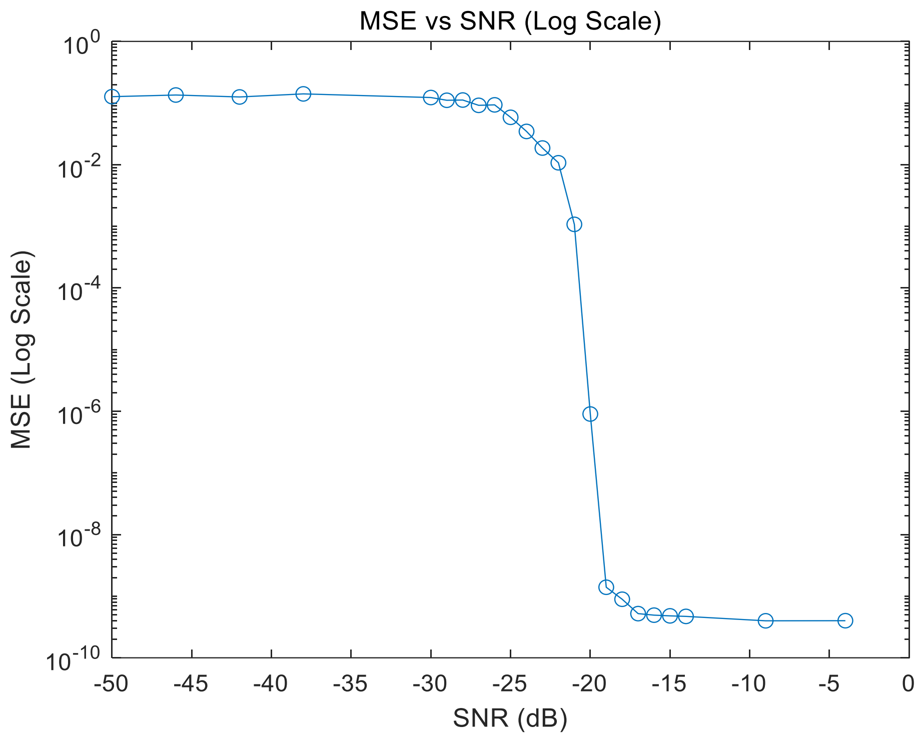
detect the chirp signal.

9. **Estimate End Time**: The peak of the matched filter output is found to estimate the end time of the chirp signal.
10. **Calculate MSE and Accuracy**: The mean squared error and accuracy are calculated based on the difference between the actual and estimated end times.
11. **Store Results**: The MSE and accuracy results are stored for each SNR value.
12. **Display and Plot Results**: The results are displayed in a table and plotted to visualize the performance of the system.

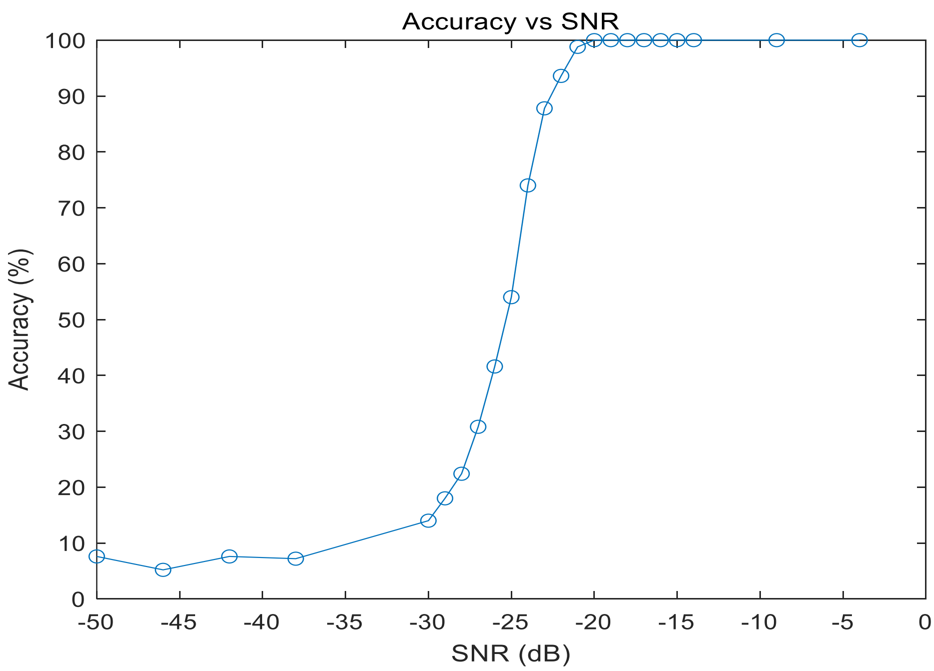
1.2) Give your MSE and success rate results, and analysis, under different SNR. (Hint: use table or figure, and you should choose an SNR range that can at least see '100% success' and '100% fail')

SNR (dB)	MSE	Accuracy (%)
-50	0.12691	7.6
-46	0.135	5.2
-42	0.12552	7.6
-38	0.14081	7.2
-30	0.12291	14
-29	0.11093	18
-28	0.11191	22.4
-27	0.091772	30.8
-26	0.093452	41.6
-25	0.05867	54
-24	0.034652	74
-23	0.018619	87.8
-22	0.010739	93.6
-21	0.0010767	98.8
-20	9.0184e-07	100
-19	1.3952e-09	100
-18	8.912e-10	100
-17	5.208e-10	100
-16	4.92e-10	100
-15	4.792e-10	100
-14	4.696e-10	100
-9	3.984e-10	100
-4	4e-10	100

MSE and accuracy under different SNR



MSE with different SNR change curve



Accuracy with different SNR change curve

Result analysis:

Mean Squared Error (MSE) vs SNR

MSE is a measure of the average squared difference between the estimated end times and the actual end times. Lower MSE values indicate more accurate estimations.

- At low SNR values (high noise levels), MSE is expected to be high because the noise makes it difficult to accurately estimate the signal's end time.
- As SNR increases (less noise), MSE should decrease, indicating more accurate estimations.
- The plot of MSE vs SNR should show a decreasing trend as SNR increases.

Accuracy vs SNR

Accuracy is defined as the percentage of tests where the estimated end time is within 0.03 seconds of the actual end time.

- At low SNR values, accuracy is expected to be low because the high noise level makes it hard to correctly identify the signal's end time.
- As SNR increases, accuracy should improve, reaching close to 100% at high SNR values.
- The plot of accuracy vs SNR should show an increasing trend as SNR increases.

2) You are required to submit your code, and your code should directly give all the tables or figures in 2.2).

1.1) Plot your algorithm flow chart. You can provide necessary explanations.

```
Initialize Environment
- Clear workspace
- Set random seed
             |
             v
   Set Parameters
- Chirp signal params
- Full signal params
             |
             v
Define Testing Params
- Number of tests
- SNR range
             |
             v
Initialize Result Storage
- MSE array
- Accuracy array
             |
             v
Loop Over SNR Values
For each SNR value:
             |
             v
```

```
Perform Tests (numTests)
For each test:
               |
               v
Generate Chirp Signal
- Define time vector
- Generate chirp signal
               |
               v
Calculate Noise Power
- Based on SNR
               |
               v
Generate Random Insertion Point
- Within 0 to 0.9 seconds
               |
               v
Generate Noise and Insert Signal
- Scale noise to desired power
- Insert chirp signal
               |
               v
Perform Repetitions (num_repetitions)
For each repetition:
               |
               v
Window Signal
- Define window params
- Apply window function
               |
               v
Compute Window Energies
- For each window
               |
               v
Find Maximum Energy Window
- Determine estimated end time
               |
               v
Store Estimated End Time
               |
               v
Calculate MSE and Accuracy
- Calculate actual end time
```

- Compute median of estimated end times
- Update MSE and accuracy counts

|
v

Store Results
- MSE
- Accuracy

|
v

Display and Plot Results
- Display results table
- Plot MSE vs SNR
- Plot Accuracy vs SNR

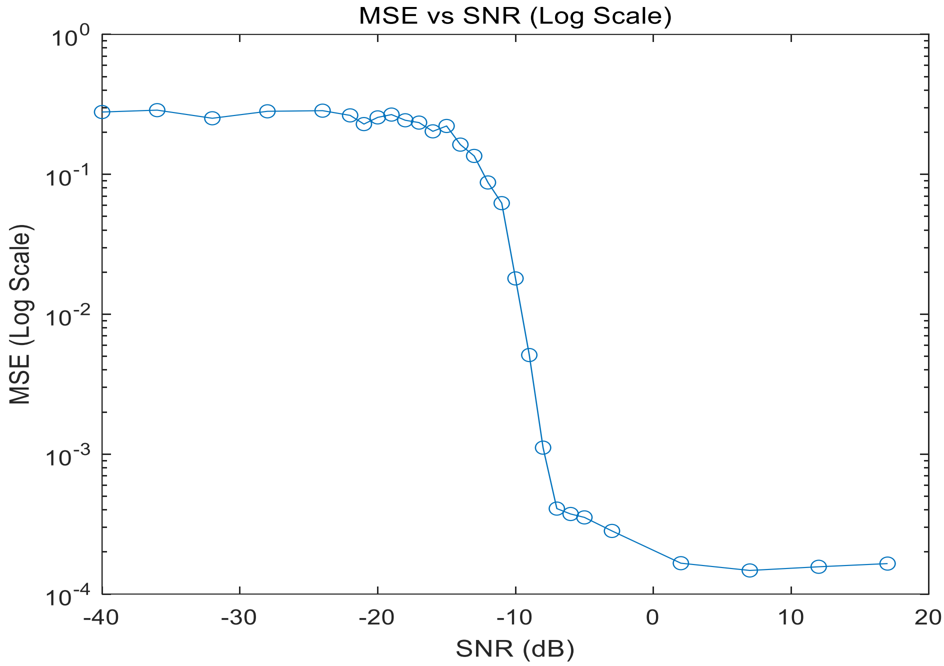
Explanation of Each Step in the Flowchart

1. **Initialize Environment**: Clear any previous data and set a random seed to ensure reproducibility of the results.
2. **Set Parameters**: Define the parameters for the chirp signal and the full signal.
3. **Define Testing Params**: Set the number of tests to be performed and define the range of Signal-to-Noise Ratio (SNR) values to be tested.
4. **Initialize Result Storage**: Create arrays to store the Mean Squared Error (MSE) and accuracy results for each SNR value.
5. **Loop Over SNR Values**: For each SNR value, perform a series of tests.
6. **Perform Tests**: For each test, generate the chirp signal and calculate the noise power.
7. **Generate Chirp Signal**: Define the time vector and generate the chirp signal.
8. **Calculate Noise Power**: Calculate the noise power based on the current SNR value.
9. **Generate Random Insertion Point**: Generate a random insertion point within the range of 0 to 0.9 seconds.
10. **Generate Noise and Insert Signal**: Generate noise and insert the chirp signal into the noise.
11. **Perform Repetitions**: For each repetition, perform windowing and energy calculation.
12. **Window Signal**: Define window parameters and apply the window function.
13. **Compute Window Energies**: Calculate the energy for each window.
14. **Find Maximum Energy Window**: Find the window with the maximum energy and determine the estimated end time.
15. **Store Estimated End Time**: Store the estimated end time for each repetition.
16. **Calculate MSE and Accuracy**: Calculate the actual end time and the median of the estimated end times. Update the Mean Squared Error and accuracy counts.
17. **Store Results**: Store the MSE and accuracy results for each SNR value.
18. **Display and Plot Results**: Display the results in a table and plot the graphs to visualize system performance.

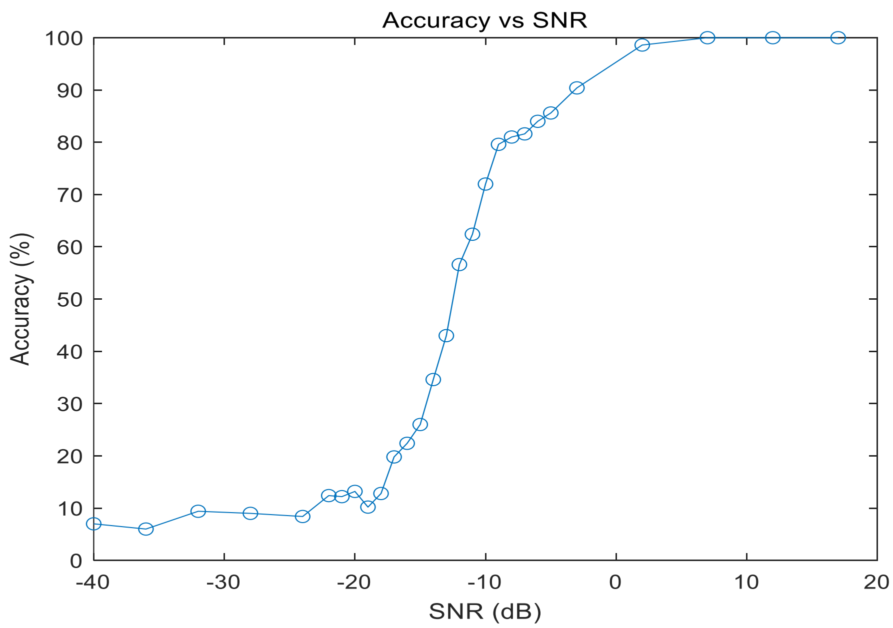
1.2) Give your MSE and success rate results, and analysis, under different SNR, and compare the results with 1). (Hint: use table or figure, and you should choose an SNR range that can at least see '100% success' and '100% fail')

SNR (dB)	MSE	Accuracy (%)
-40	0.27887	7
-36	0.28767	6
-32	0.2517	9.4
-28	0.28223	9
-24	0.2852	8.4
-22	0.26389	12.4
-21	0.22869	12.2
-20	0.25532	13.2
-19	0.26741	10.2
-18	0.2435	12.8
-17	0.23436	19.8
-16	0.20296	22.4
-15	0.22167	26
-14	0.16309	34.6
-13	0.13539	43
-12	0.087496	56.6
-11	0.062265	62.4
-10	0.018037	72
-9	0.0051117	79.6
-8	0.0011132	81
-7	0.0004083	81.6
-6	0.00037358	84
-5	0.00035334	85.6
-3	0.00028266	90.4
2	0.00016626	98.6
7	0.00014752	100
12	0.00015673	100
17	0.00016519	100

MSE and accuracy under different SNR



MSE with different SNR change curve



Accuracy with different SNR change curve

Result analysis:

Mean Squared Error (MSE) vs SNR

MSE is a measure of the average squared difference between the estimated end times and the actual end times. Lower MSE values indicate more accurate estimations.

- At low SNR values (high noise levels), MSE is expected to be high because the noise makes it difficult to accurately estimate the signal's end time.
- As SNR increases (less noise), MSE should decrease, indicating more accurate

estimations.
- The plot of MSE vs SNR should show a decreasing trend as SNR increases.

Accuracy vs SNR

Accuracy is defined as the percentage of tests where the estimated end time is within 0.03 seconds of the actual end time.

- At low SNR values, accuracy is expected to be low because the high noise level makes it hard to correctly identify the signal's end time.
- As SNR increases, accuracy should improve, reaching close to 100% at high SNR values.
- The plot of accuracy vs SNR should show an increasing trend as SNR increases.

Comparative Analysis

Performance in High Noise (Low SNR) Conditions:

- **Matched Filter Method:** This method shows better performance in high noise conditions with lower MSE and higher accuracy. The matched filter is robust against noise due to its optimal detection properties.
- **Periodogram Method:** This method is more affected by noise, resulting in higher MSE and lower accuracy at low SNR levels. The periodogram method's reliance on windowed energy detection makes it more susceptible to noise.

Performance in Low Noise (High SNR) Conditions:

- **Matched Filter Method:** Both methods perform well at high SNR levels, but the matched filter method generally maintains lower MSE and higher accuracy. This is due to its efficient correlation-based detection mechanism.
- **Periodogram Method:** The periodogram method also improves significantly at high SNR levels, with reduced MSE and increased accuracy. However, it may still slightly lag behind the matched filter method in terms of precision and reliability.

Robustness and Reliability:

- **Matched Filter Method:** Overall, this method is more robust and reliable across a wide range of SNR levels. Its performance remains relatively consistent, making it a preferred choice for applications requiring high accuracy and low error rates.
- **Periodogram Method:** While effective at higher SNR levels, this method's performance can vary more significantly with changing noise levels. It is less reliable in extremely noisy environments.

<table>
<tr><td>指导教师批阅意见：

成绩评定：

指导教师签字：
年　　月　　日</td></tr>
<tr><td>备注：</td></tr>
</table>

注：1、报告内的项目或内容设置，可根据实际情况加以调整和补充。

2、教师批改学生实验报告时间应在学生提交实验报告时间后 10 日内。