Digital Filtering Techniques in MATLAB Tutorial

Open the Filter Designer app by typing FilterDesigner in the MATLAB command window and pressing Enter. Alternatively, you can click on the "Apps" tab in the MATLAB Toolstrip, navigate to the "Signal Processing and Communications" section, and click on the "Filter Designer" app icon. Reference Figures 1 and 2.

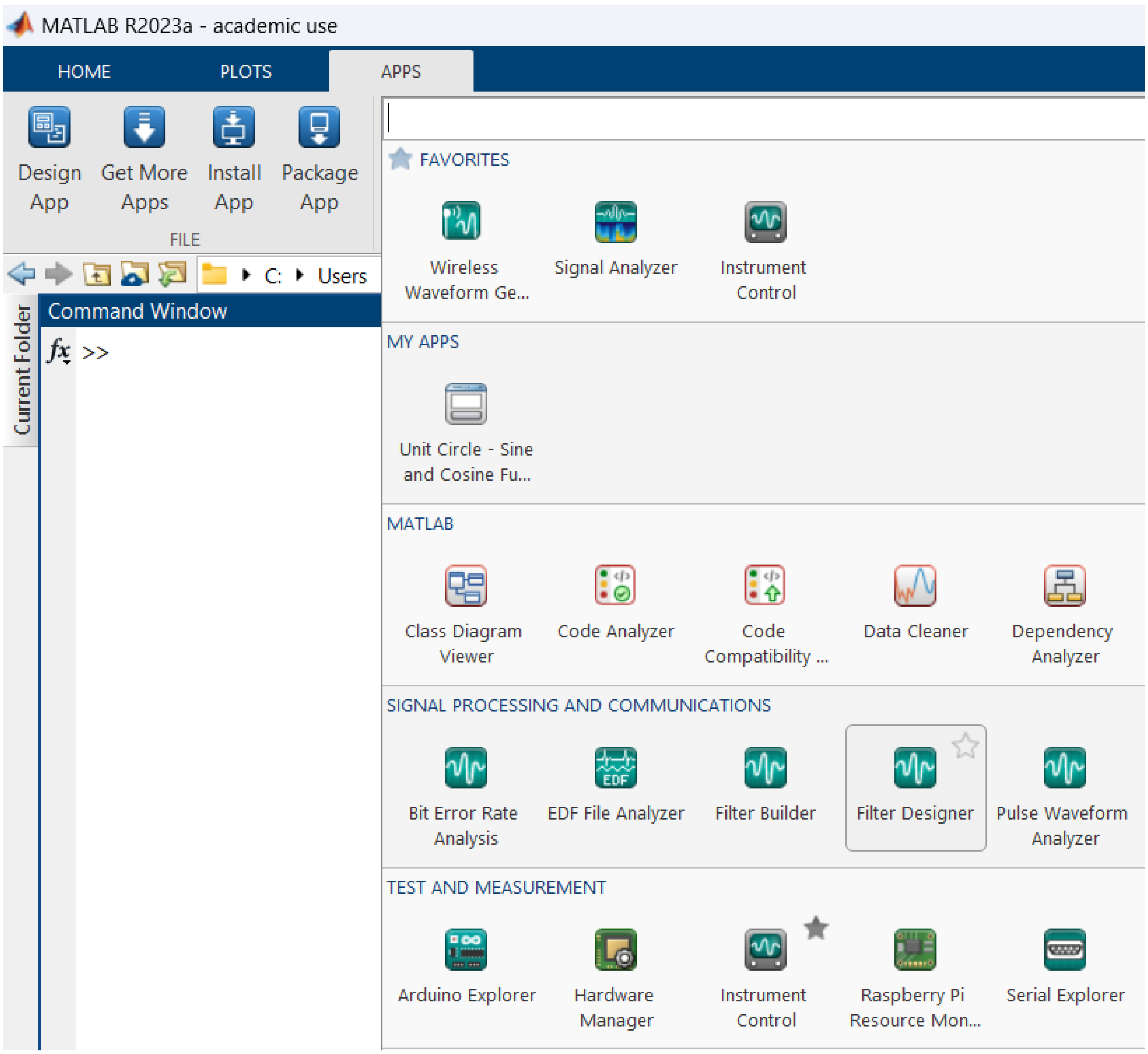

Figure 1: Filter Designer App in MATLAB

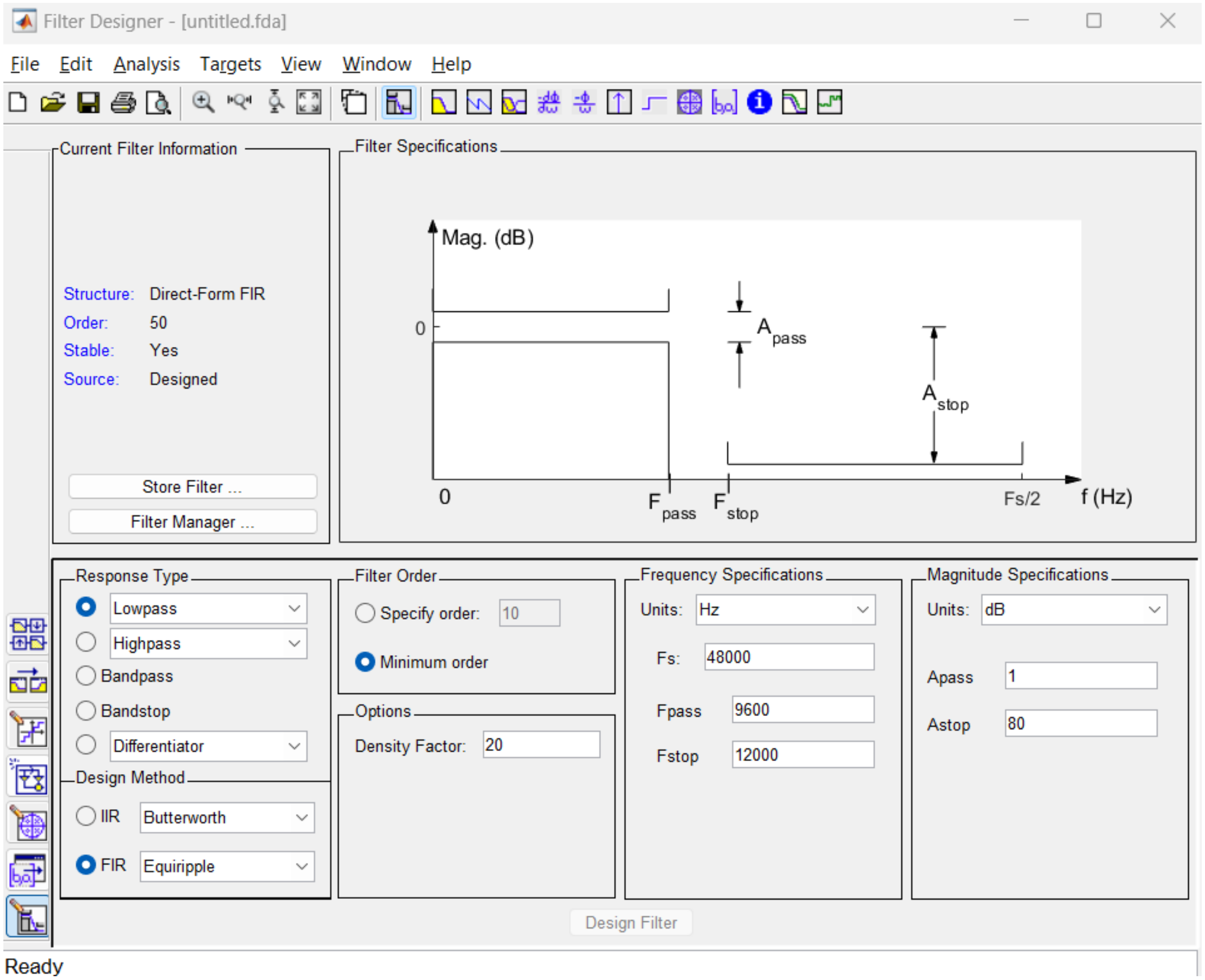

Figure 2: Filter Designer App Interface

Design Steps:

Once the app is open, you can select the type of filter you want to design from the "Filter Type" drop-down menu, such as lowpass, high-pass, bandpass, or band-stop.

1) **Low-pass Filter:**
   A low-pass filter is a filter that allows signals with a frequency lower than a certain cutoff frequency to pass through and attenuates signals with frequencies higher than the cutoff frequency.
   Cutoff frequency: The frequency at which the filter starts attenuating higher frequencies. This is usually defined as the frequency at which the filter's gain falls to 3 dB below its maximum value.

2) **High-pass Filter:**

A high-pass filter is a filter that allows signals with a frequency higher than a certain cutoff frequency to pass through and attenuates signals with frequencies lower than the cutoff frequency.
Cutoff frequency: The frequency at which the filter starts attenuating lower frequencies. This is usually defined as the frequency at which the filter's gain falls to 3 dB below its maximum value.

3) **Passband Filter:**
A bandpass filter is a filter that allows signals within a specific frequency range (band) to pass through while attenuating signals outside this range.
Cutoff frequency range: The range of frequencies that the filter allows to pass through. This is typically specified by a lower and upper cutoff frequency.

4) **Band-stop Filter:**
A band-stop filter is a type of electronic filter that attenuates frequencies within a specific range (the stopband), while allowing frequencies outside that range to pass through.
Cutoff frequency range: The range of frequencies that the filter will attenuate. This is typically specified by a lower and upper cutoff frequency.

Filters Specifications:

Sampling frequency: The rate at which a continuous-time signal is sampled to convert it into a discrete-time signal.

Passband ripple: The allowable variation in gain in the passband (the range of frequencies below the cutoff frequency). This is specified in dB.

Stopband attenuation: The minimum amount of attenuation required in the stopband (the range of frequencies above the cutoff frequency).

Transition band: The range of frequencies over which the filter transitions from the passband to the stopband. This specifies how sharp the cutoff is.

Filter order: The order of the filter based on the desired transition band and stopband attenuation. Higher-order filters may introduce more delay or complexity.

Specify the filter parameters such as the passband frequency, stopband frequency, passband ripple, and stopband attenuation.

Choose the design method from options such as Butterworth, Chebyshev Type I or II, Elliptic, or FIR filter designs.

Finite Impulse Response (FIR) filters have a finite impulse response and are widely used in SDRs due to their linear phase response and stability.

Infinite Impulse Response (IIR) filters have an infinite impulse response and are more computationally efficient than FIR.

Adjust additional parameters such as filter order, and filter response type as needed.

Determine the filter order: Based on the specifications for the transition band and the required stopband attenuation, determine the order of the filter.

Design the filter: Once the design parameters/filter specifications are set, click “Design Filter” to calculate the coefficients for the filter. Reference Figures 3, 4, 5, and 6.

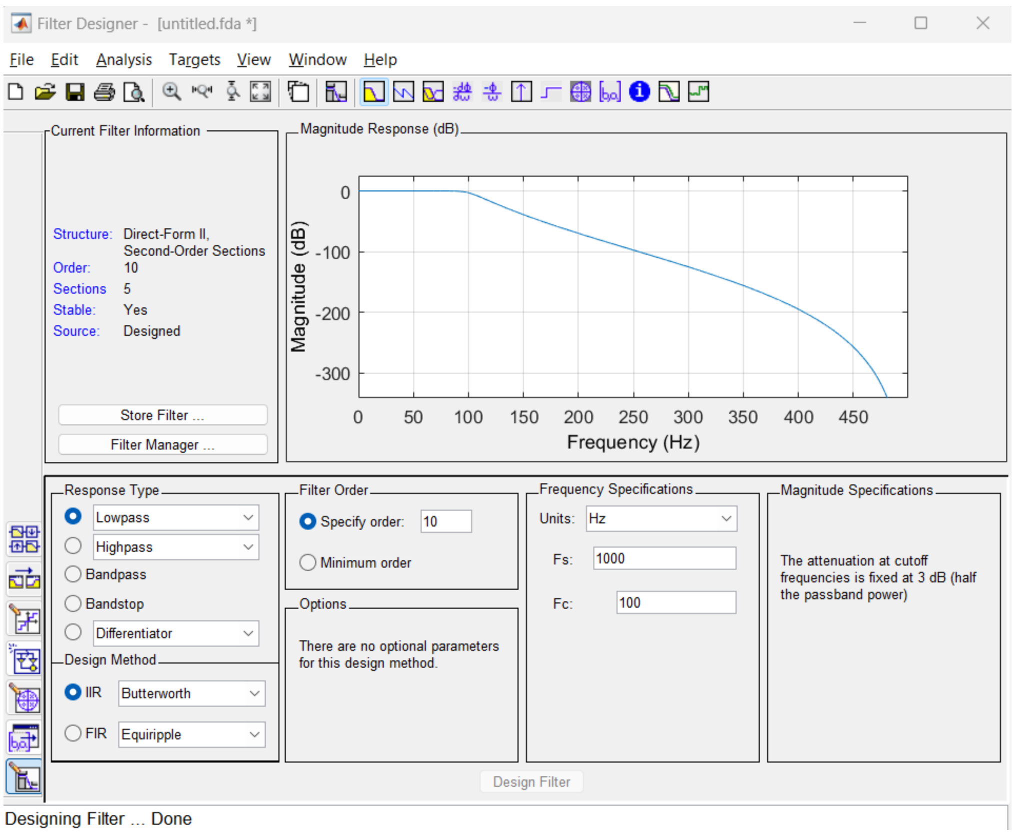

Figure 3: Example of Low Pass Filter

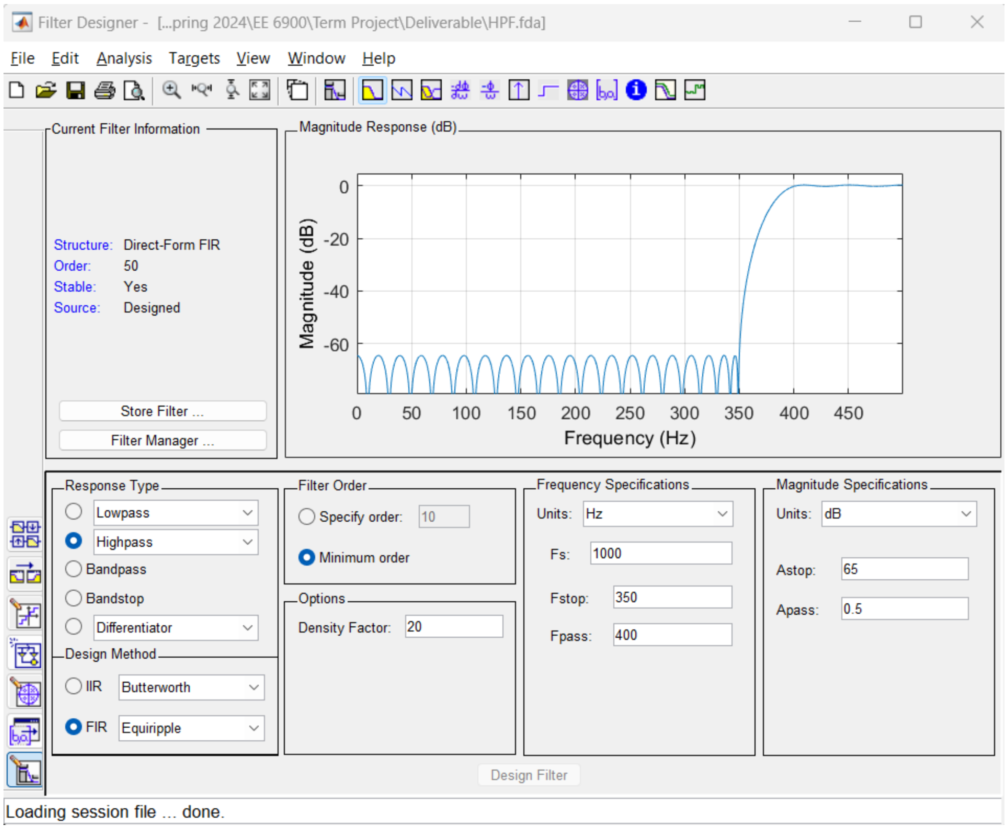

Figure 4: Example of High Pass Filter

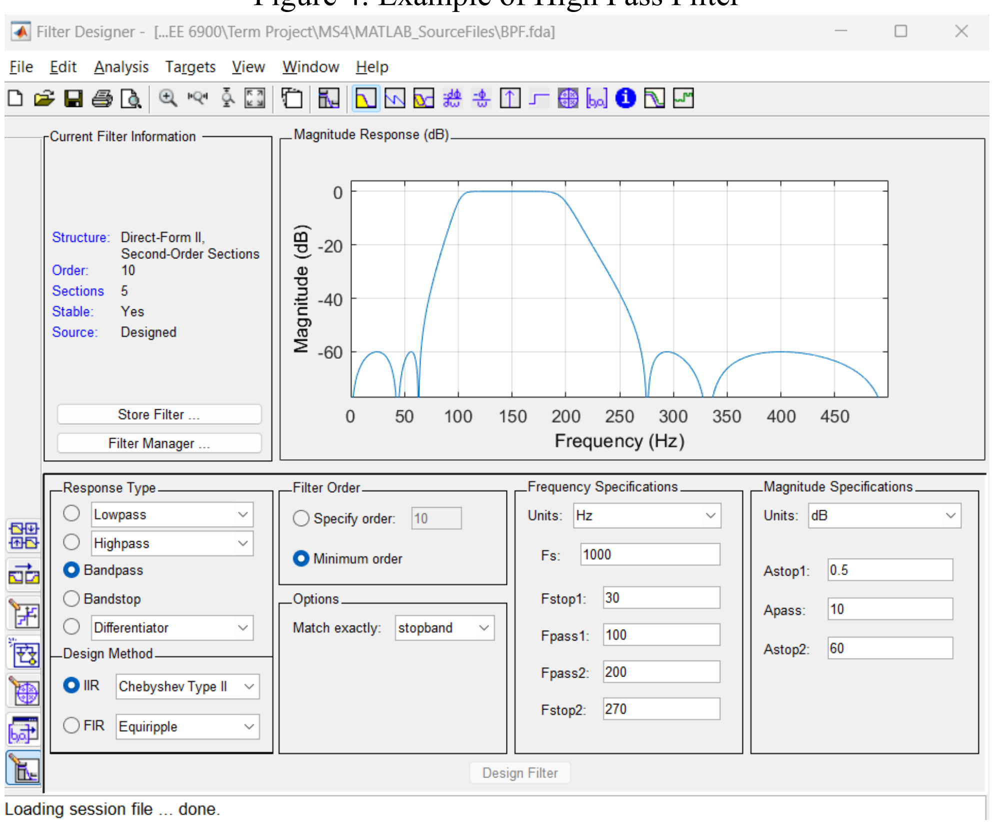

Figure 5: Example of Bandpass Filter

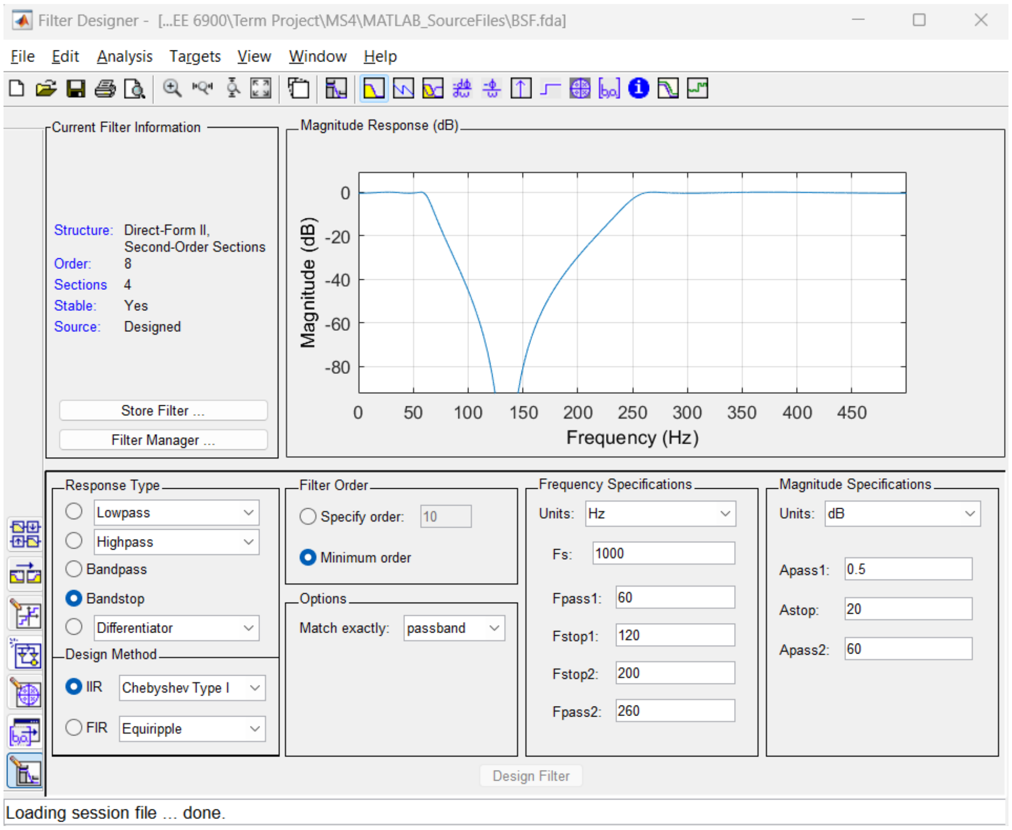

Figure 6: Example of Band Stop Filter

The app provides visualizations of the filter response in both the time domain and frequency domain. You can view the impulse response, step response, magnitude response, phase response, and pole-zero plot of the designed filter.

Use the "View" menu or the tool bar to toggle between different response plots and customize their appearance. Reference Figure 7.

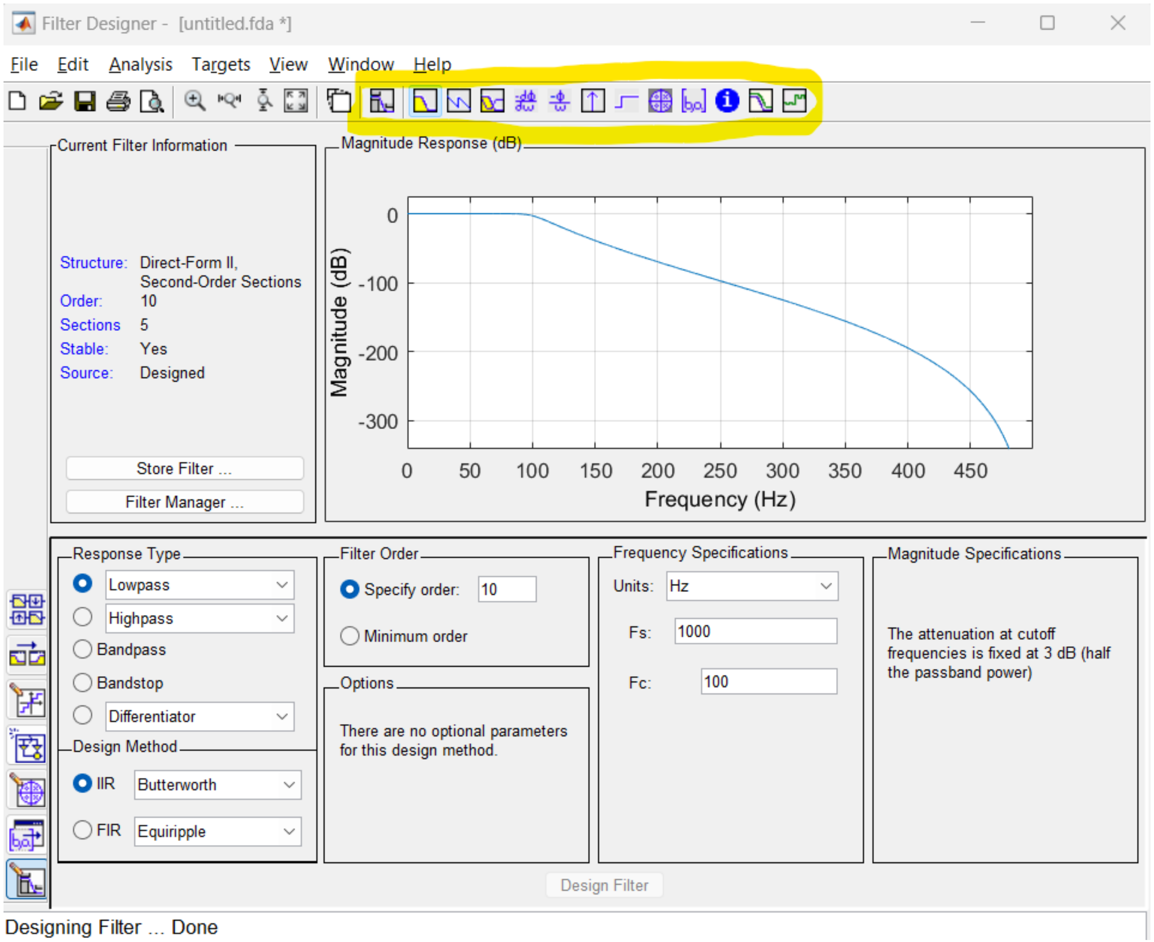

Figure 7: Visualization of the Filter Response

Once you are satisfied with the filter design, you can export the filter coefficients or filter object to the MATLAB workspace for further implementation in your MATLAB code. Remember the Filter variable name for usage later in filter implementation. Reference Figure 8.

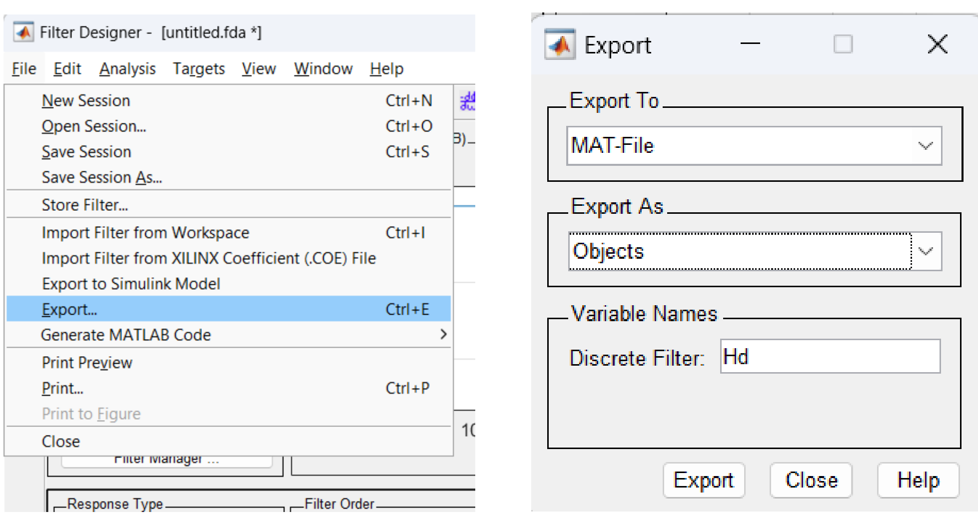

Figure 8: Exporting Filter

You can save your filter design projects in .fda files for future reference or modification. Use the "File" menu to save the project.

Wireless Waveform Generator

The Wireless Waveform Generator app in MATLAB allows users to generate and visualize wireless waveforms for various communication standards and scenarios. Here's how you can use the Wireless Waveform Generator app:

Select the "Apps" tab in the MATLAB Toolstrip and click on the " Wireless Waveform Generator" app icon. Reference Figure 9.

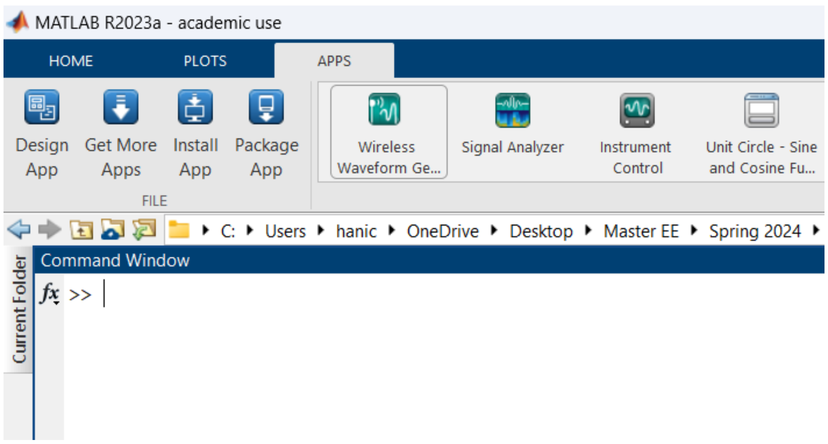

Figure 9: Lunching Wireless Waveform Generator App

Select QAM (quadrature amplitude modulation), then configure the parameters, such as modulation order, symbol mapping, and output symbol rate. Reference Figure 10.

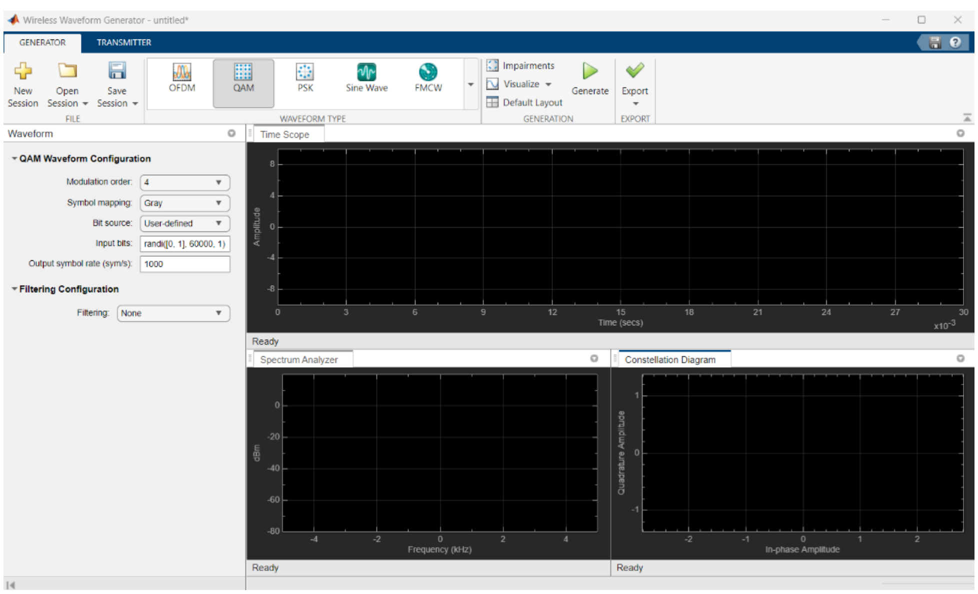

Figure 10: QAM Interface

The App allows users to add impairments such as AWGN or frequency offset. Reference Figure 11.

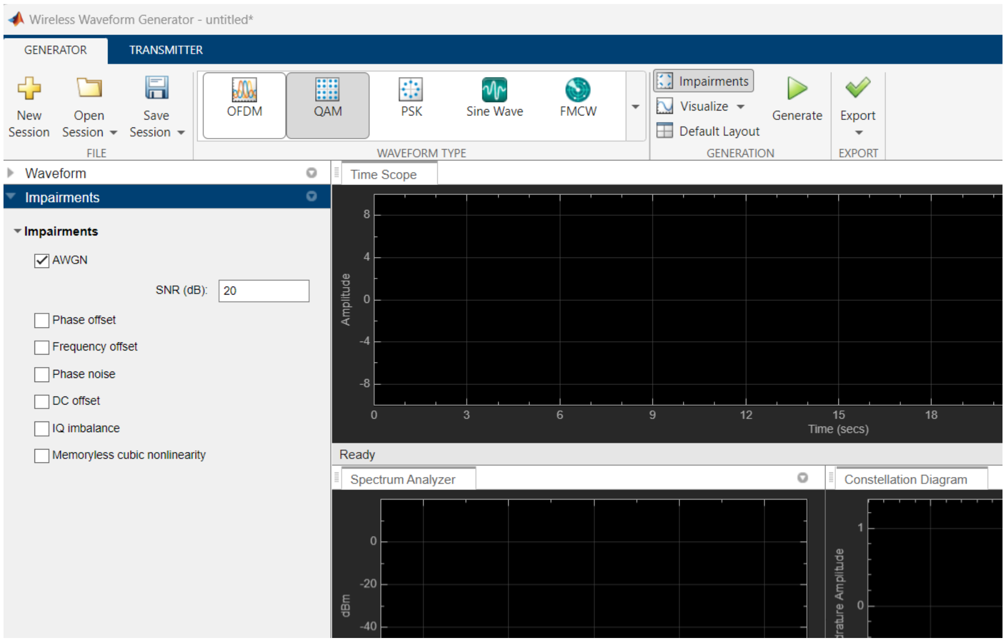

Figure 11: Adding Impairments

After configuring the parameters, click the "Generate" button to generate the waveform based on the specified settings. The waveform will be displayed in the app's waveform viewer that displays the time-domain waveform, frequency spectrum, and constellation diagram. Reference Figure 12.

You can save the generated waveform to a MATLAB variable and export it as MATLAB script file for further analysis or simulation in MATLAB. Reference Figure 13.

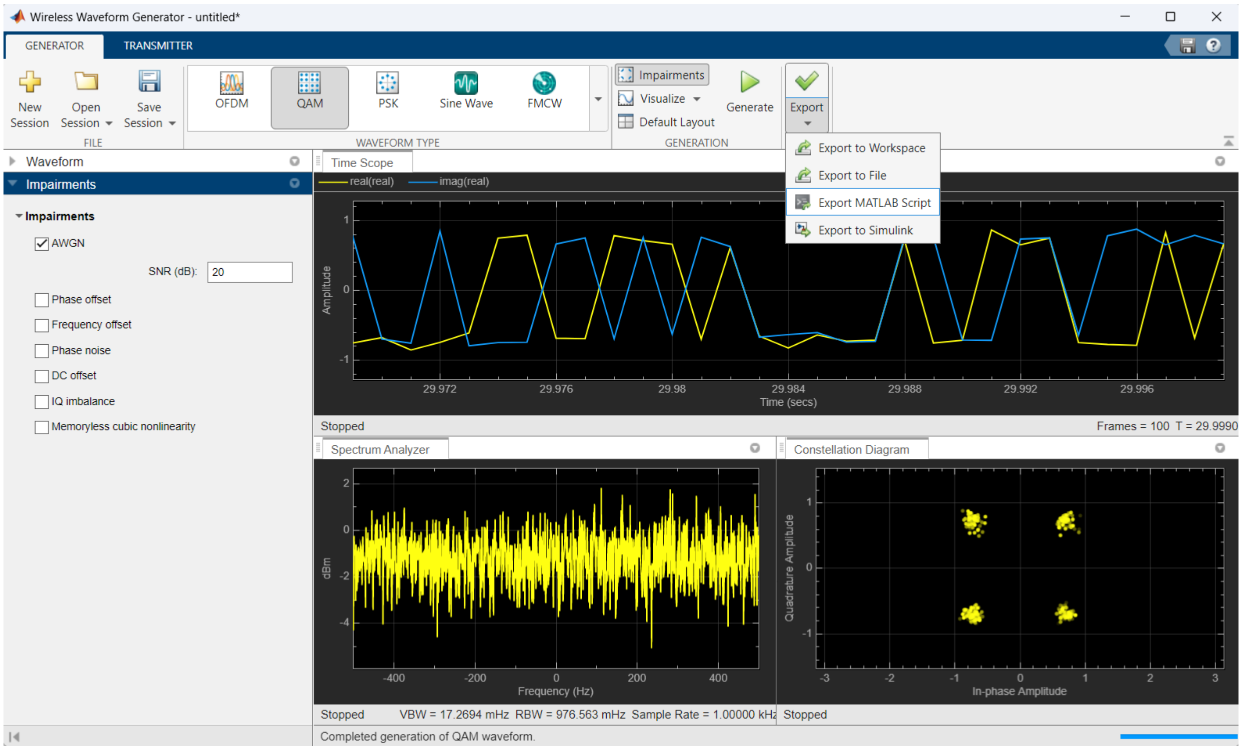

Figure 12: Exporting Generated Waveform

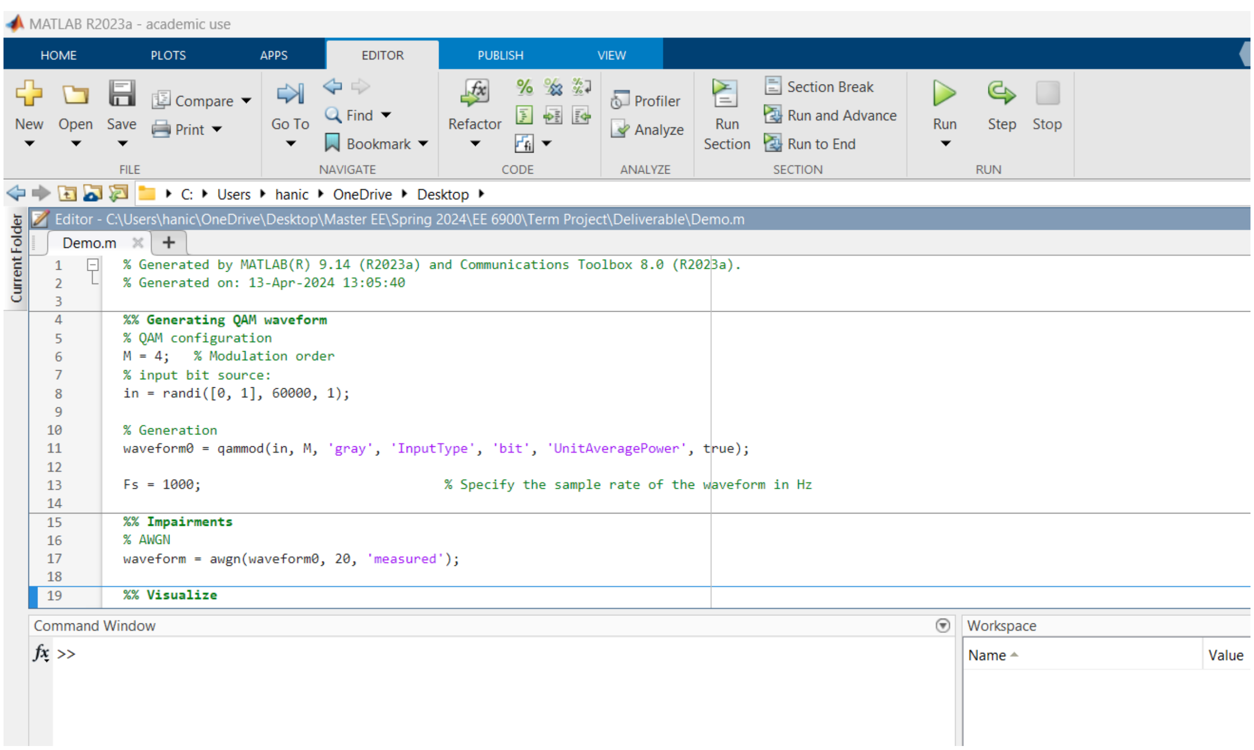

Figure 13: Example of Exported Waveform

Filter Implementation

To load the filter, simply type load and the name of the filter file to load it into the workspace. Use the filter function to apply the filter object designed earlier to the generated waveform. Reference Figure 14.

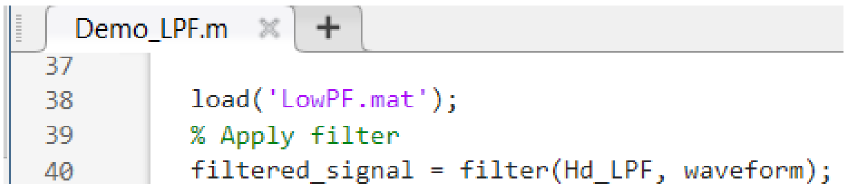

Figure 14: Loading Data and Applying Filter

MATLAB script file can be customized to add additional spectrum analyzers, and figures for visualization purposes. Reference Figure 15.

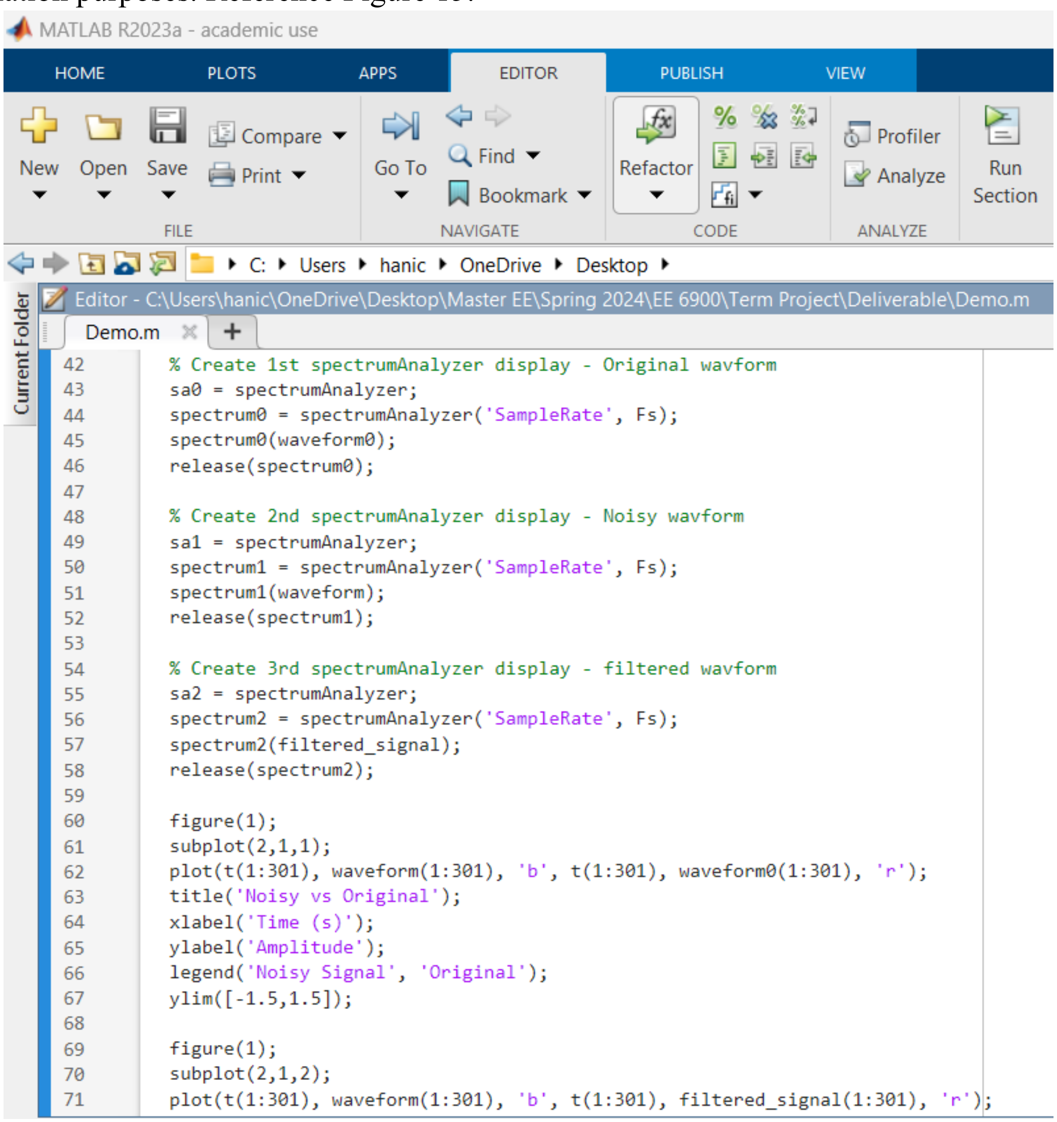

Figure 15: Adding Spectrum Analyzers

Run the code to observe the outcome of the filter response. Reference Figures 16, 17, 18, 19, and 20 for the generated waveform, and Lowpass filter response.

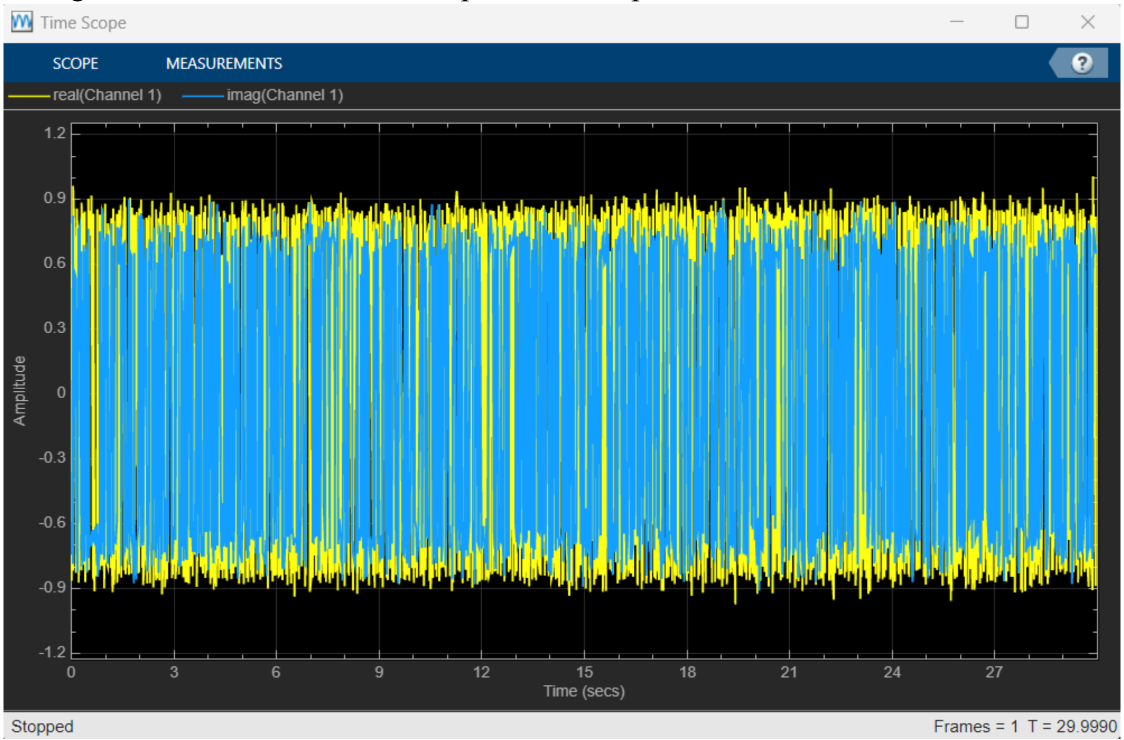

Figure 16: Time Scope of the Generated Waveform

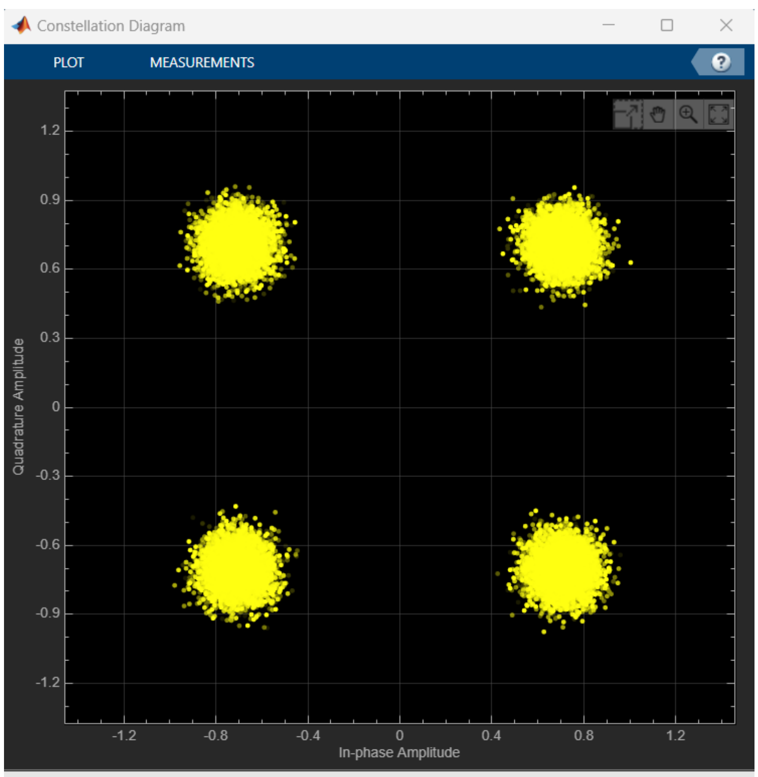

Figure 17: Constellation Diagram

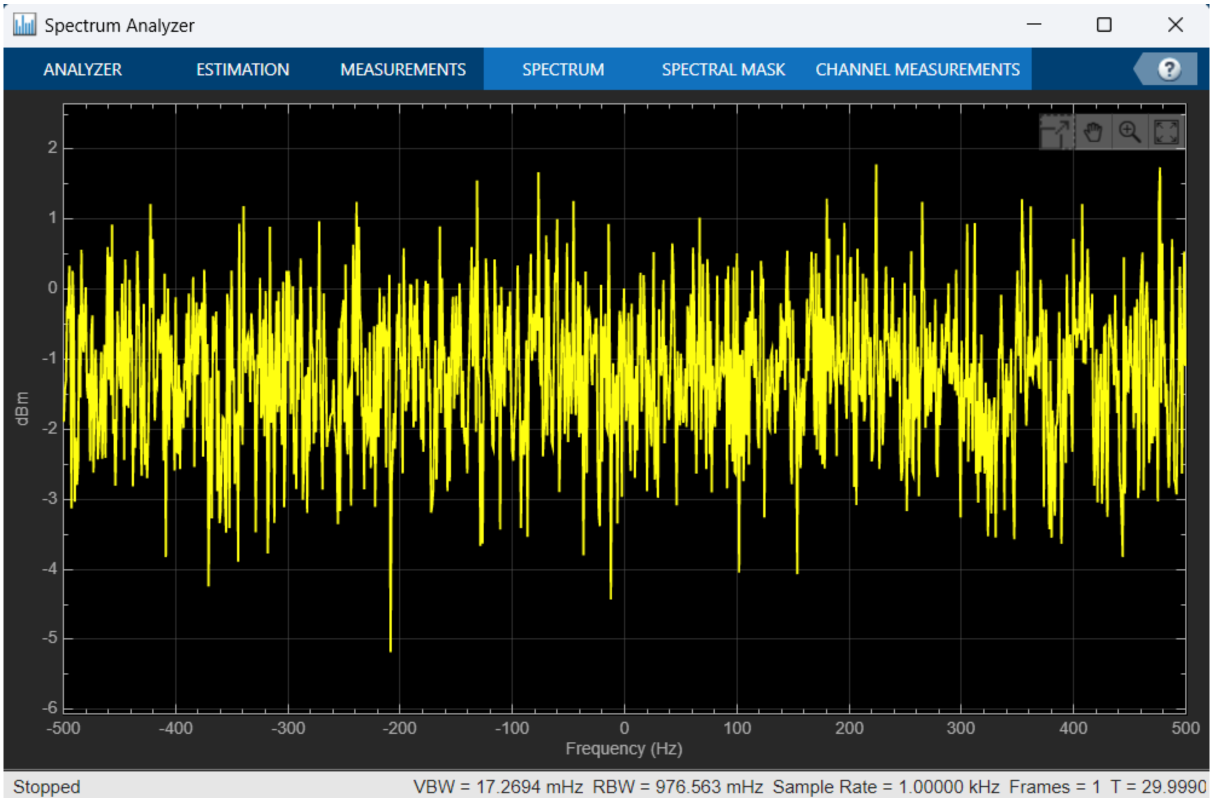

Figure 18: Spectrum Analyzer without Filter

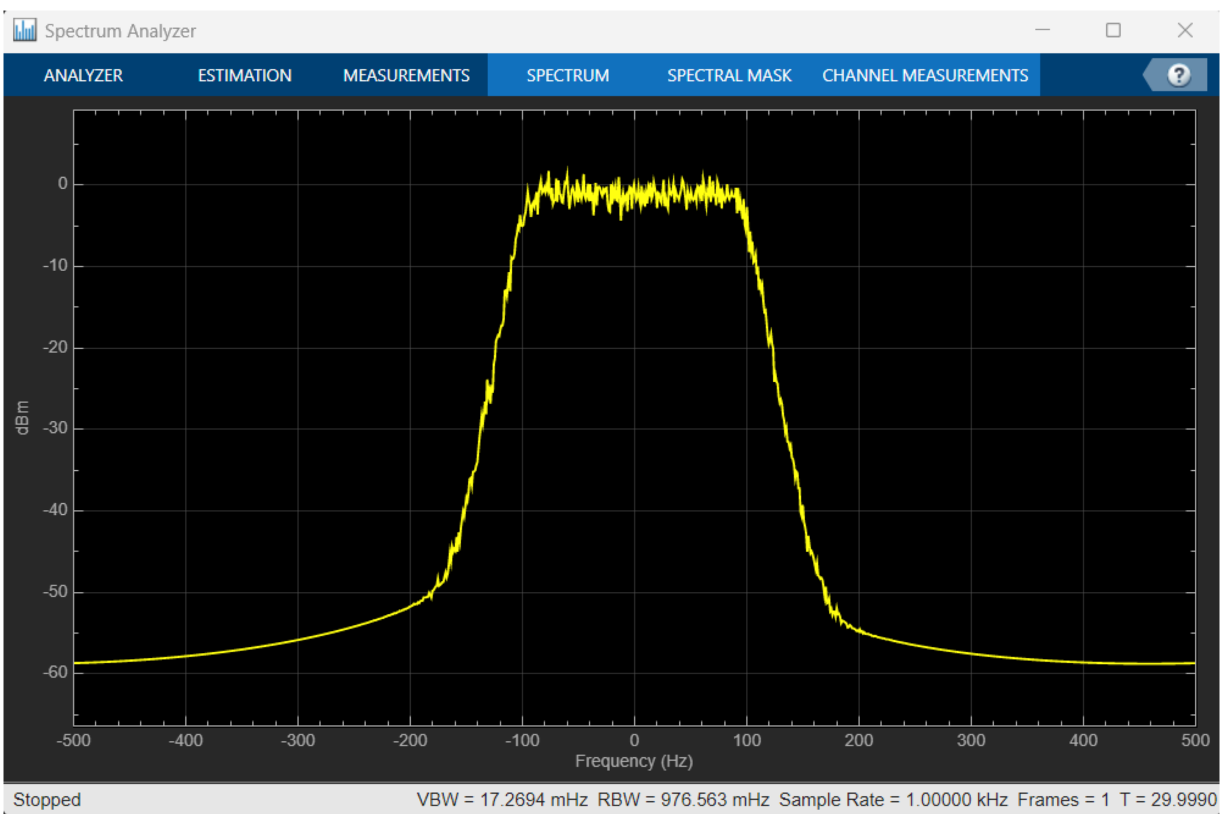

Figure 19: Spectrum Analyzer with Lowpass Filter

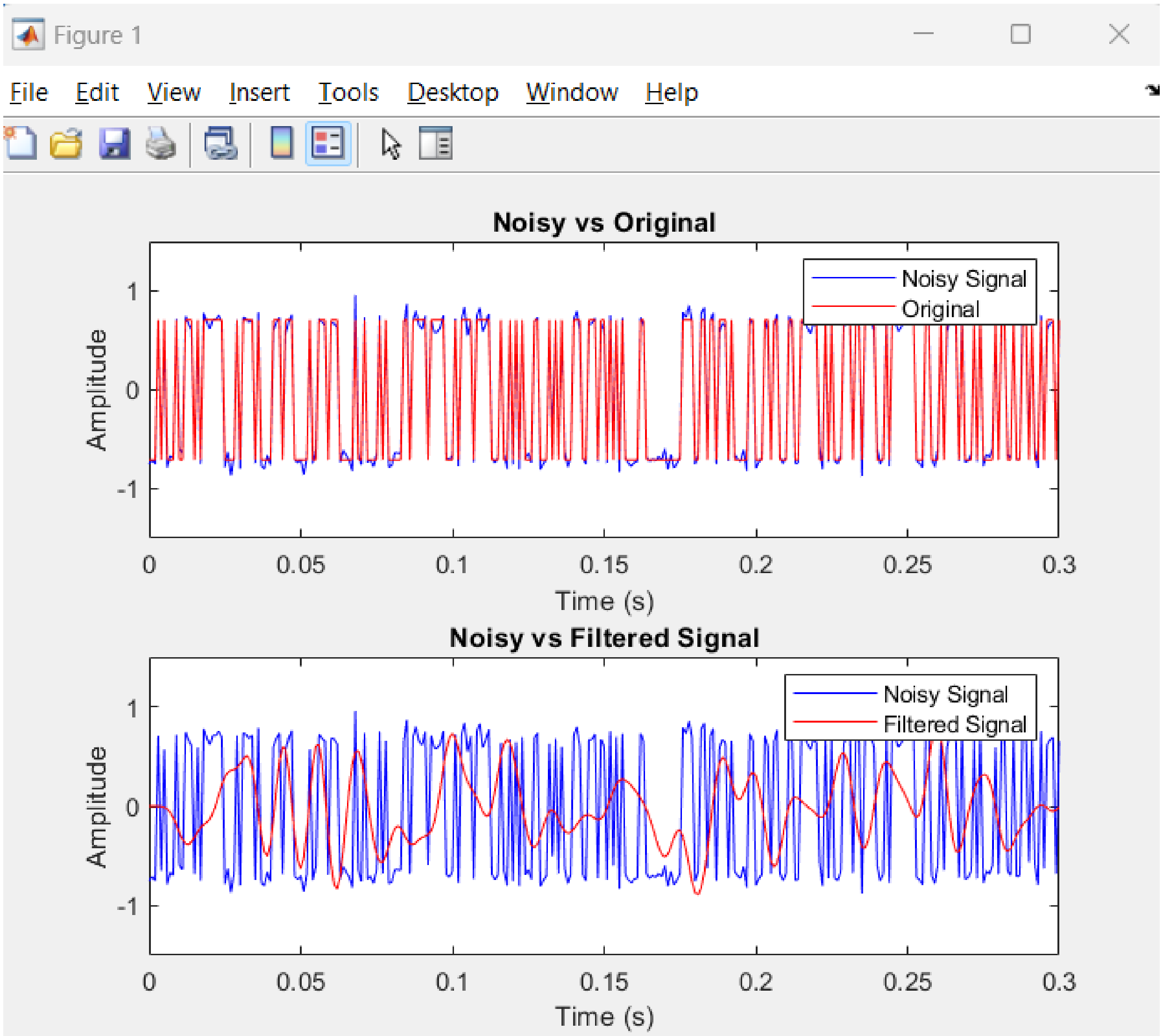

Figure 20: Comparison of Noisy Waveform vs Original Waveform vs Filtered Waveform