

Lab 11: Signal Spectrum and Filtering

Materials:

- Time Domain P410 radar
- MRM RET software
- USB 2.0 A to Micro-B cable.
- Metal Sphere
- Tape measure

Introduction:

In this laboratory we will calculate the spectrum of the received signal. We will then filter the data, first using a lowpass filter, then a highpass filter, and observe the effects of the filters on the resulting spectrum and the time domain signal.

The spectrum of a signal refers to a plot of the magnitude and phase response of different frequency components. The spectrum of the signal will be calculated using the fast Fourier transform (FFT) which is an efficient method of implementing the discrete Fourier transform (DFT), given by

$$X(m) = \sum_{n=0}^{N-1} x(n)e^{-j2\pi nm/N}$$

From Euler's relationship, $e^{-j\varphi} = \cos(\varphi) - j \sin(\varphi)$, we can see that each $X(m)$ DFT output term is the sum of the point-for-point product between an input sequence of signal values and a complex sinusoid of the form $\cos(\varphi) - j \sin(\varphi)$. The exact frequencies of the different sinusoids depend on both the sampling rate f_s at which the original signal was sampled, and the number of samples, N . The fundamental frequency of the sinusoids is f_s/N . The other $X(m)$ analysis frequencies are integral multiples of the fundamental frequency.

Experiment:

For this experiment we will collect the data using a Time Domain P410 MRMRET module to illuminate a spherical target and collect the radar return data. This data will subsequently be processed using MATLAB.

1. Apply power to the MRM, start MRM RET and connect to the MRM.
2. Set the **Transmit Gain** to 0 so that received signals due to close targets are not saturated.

3. Set the **Scan Start** time to the value calculated in Experiment 8. Set the **Scan Stop** time to give a maximum range of approximately 2 meters.
4. Take a background scan with no target present. Log the data and note the file name.
5. Place a sphere at a distance of approximately 1 meters from the face of the antenna. Measure the actual distance with a tape measure. Take a scan with the target in place and log the data. Name this file “target.csv” or equivalent.
6. In Matlab open the *Experiment8.m* file and save the file as *Experiment11.m*
 - a. Use the code to open both files and calculate the difference scans.
 - b. Pick one difference scan to work with. Plot this scan and verify the target is at the location you expect.
 - c. Use the MATLAB `fft()` command to determine the spectrum of the signal.
 - i. Plot the magnitude spectrum using the `abs()` command. Use the correct frequency axis.
 - ii. Shift the spectrum using the `fftshift()` command. This will center the spectrum at 0 frequency. Read the `fftshift` help page to better understand this function.
 - iii. Plot the magnitude spectrum. Use the correct frequency axis. Recall, the sampling time is given by T_{bin} (given in nanoseconds) in the code (approximately 61 picoseconds). What range of frequencies are present in the signal?
7. Design a low pass filter for this signal. Set the pass band frequency to 4.9 GHz and the stop band frequency to 5.6 GHz. Allow for 1 dB of attenuation in the pass band and require at least 20 dB of attenuation in the stop band.
 - a. First design a Butterworth filter. Use the command `buttord()` to determine the order and the normalizing frequency for the filter. See the MATLAB help file to determine how to use this command. MATLAB expects normalized frequencies which are frequencies in radians divided by π . So your pass band frequency will become

$$\Omega = 2\pi f T_s$$
 where f is the frequency of interest in Hz and T_s is your sampling frequency. Use `[Num,Den]=butter()` to determine the numerator and denominator coefficients of your filter. Again see the help file for more information on the `butter()` command.
 - b. Filter the difference scan from 6. Use the command `filter(Num,Den,data)` where Num and Den are the numerator and denominator coefficients of the filter, and data is your difference scan. Save the filtered data to another vector. Plot the shifted magnitude spectrum and compare your results to the results from 6.c.iii

- c. Plot the time domain scan difference as well as the filtered signal on the same plot. Discuss the effects of the filter on the signal as viewed in the time domain.
8. Design a Butterworth high pass filter for the filtered data from 7. The filter should have a pass band cutoff frequency of 0.1 GHz and a stop band cutoff frequency of 0.05 GHz. Again, allow for 1 dB of attenuation in the pass band and require at least 20 dB of attenuation in the stop band. Consult the butter help file to determine how to design a high pass filter.
 - a. Repeat 7.b and 7.c using this filter on your low pass filtered data (not the original scan).
9. Repeat 7 and 8 but with a filter of a different type. You may use a Chebyshev type I or II or an elliptic filter.

Questions:

1. Explain the frequency spectrum that you see in part 6.c.i. There appears to be frequency content above about 8.2GHz. Explain why this is not accurate.
2. Explain the purpose of the fftshift command. How is the plot obtained in 6.c.iii different than that from 6.c.i?
3. Describe the effects of the low pass filter on your data. Consider both the time and frequency domain.
4. Describe the effects of the high pass filter on your data. Consider both the time and frequency domain.
5. What order do you need for your different filters? Do you notice any difference between the performance of the Butterworth filter and the other filter you chose in part 8?

Turn in:

Plots from 6, 7, and 8 as well as your responses to the questions.