Project report
on
Delay Line Cancellers (DLC)

EED374 Radar Engineering
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Submitted by

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INTRODUCTION

Delay line cancellers are widely used in digital communication and radar systems to mitigate the effects of channel distortion and unwanted echoes or interference, respectively. In radar systems, a delay line canceller is a specific signal processing technique that removes unwanted echoes or interference from the received radar signal. The delay line canceller works by introducing a delay into the received signal, matching the delay of the unwanted echoes or interference, and subtracting the delayed signal from the original received signal. This cancels out the unwanted echoes or interference, leaving only the desired signal.

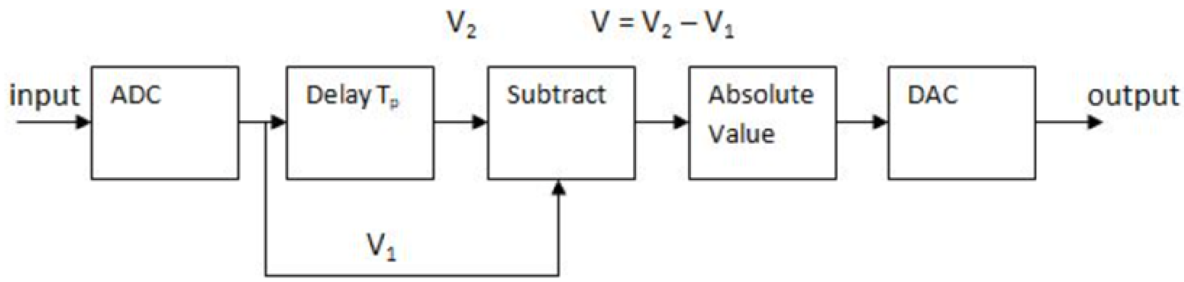
This project uses MATLAB and Simulink simulations to explore the design and performance of delay line cancellers. We shall first describe the theory surrounding delay line cancellers and other relevant mathematical expressions, which are expanded upon by various simulated results. We will also briefly discuss the simulation environment, set-up parameters, and workarounds to problems faced in the design phase.

Additionally, we will demonstrate the effectiveness of the designed delay line canceller in a fictional MTI radar system. The simulation results will showcase the cancellation of unwanted echoes or interference, resulting in a cleaner received signal with improved target detection.

This project thoroughly analyzes delay line cancellers and their use in radar systems. We can validate the theoretical findings and learn more about the practical performance of delay line cancellers in real-world situations thanks to MATLAB and Simulink simulations.

DESIGN:

DLCs work by introducing a time delay into the received signal using a delay line. The delay line can be a simple circuit that delays the signal by a fixed amount of time or a more complex circuit that can vary the delay time based on the signal's characteristics. The delayed signal is then subtracted from the original signal using a subtractor circuit. The subtractor circuit can be a simple difference amplifier or a more complex circuit that removes unwanted signals with different delay times.



Delay Line Canceller Block Diagram

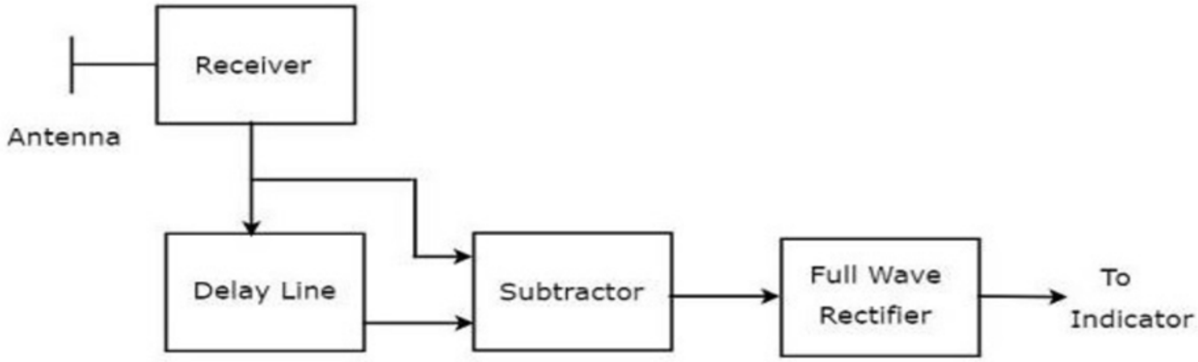
The output of the MTI radar is given as input to the delay line canceller. An analog-to-digital converter converts the input signal to its equivalent digital value. The signal is delayed, which is achieved by storing the radar output during the pulse transmission. The original signal and delayed version are then subtracted to produce an output signal free from echoes. The absolute value of the difference signal is then taken and fed to a digital-to-analog converter to produce the output signal.

Types of Delay Line Canceler-
Delay line cancellers can be classified into types based on the number of delay lines.

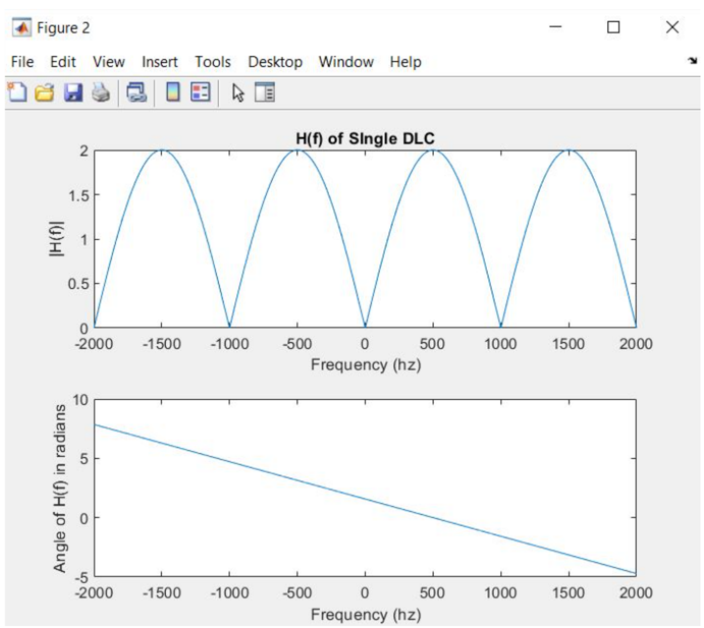
Single Delay Line Canceller- A Single Delay Line Canceller (SDLC) is a type of delay line canceller that uses a single delay line to remove unwanted echoes and interference from a received signal. It is a relatively simple and low-cost implementation of the delay line canceller technique.

In an SDLC, the delay line introduces a fixed time delay into the received signal, which is typically set to match the delay time of the unwanted signal. The delayed signal is then subtracted from the original signal using a subtractor circuit, leaving only the desired signal.

The main advantage of an SDLC is its simplicity and low cost. It can be easily implemented using analog circuitry and does not require complex digital signal processing algorithms. However, its performance may be limited by the fixed delay time, which may only be optimal for some signal conditions. Additionally, SDLCs may be less effective at canceling unwanted signals with varying or non-repeating delay times.
The block diagram of SDLC is shown below:



The transfer function plot for Single Delay Line Canceler simulate in MATLAB Simulink is-

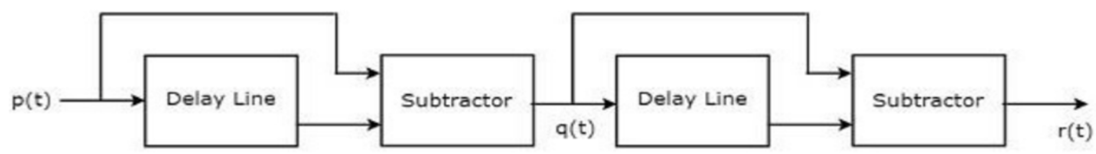


Double Line Canceller- A Double Line Canceller (DLC) is a delay line canceller that uses two delay lines to remove unwanted echoes and interference from a received signal. The two delay lines are typically designed to introduce different delay times into the received signal, allowing for more precise cancellation of unwanted signals with varying delay times.

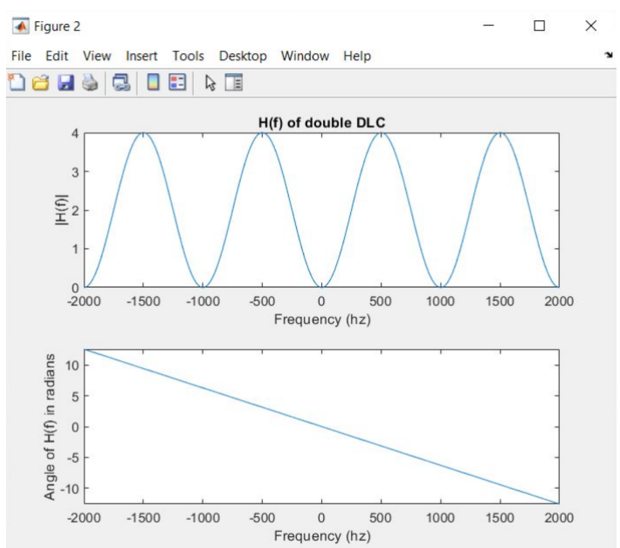
In a DLC, the received signal is split into two paths, one passing through a short delay line and the other through a long delay line. The delayed signals are then subtracted from the original signal using a subtractor circuit. By adjusting the delay times of the two delay lines, the DLC can effectively cancel out unwanted signals with varying delay times.

The main advantage of a DLC over a single-delay line canceller is its improved cancellation performance for signals with varying delay times.

The block diagram of the double-line canceller is shown below:



The Bode plot for Double Delay Line Canceler is -



N- Delay Line Canceler-

Similarly, we can make N line delay line canceller. In an N-Line Delay Line Canceller, the received signal is split into multiple paths, each passing through a different delay line with a different delay time. The delayed signals are then combined and subtracted from the original signal using a subtractor circuit.

The N-Line Delay Line Canceller can effectively cancel out unwanted signals with varying delay times and improve cancellation performance by using multiple delay lines with different delay times.

N-Line Delay Line Cancellers are typically used in high-performance radar or sonar systems. Precise cancellations of unwanted echoes and interference are essential for accurately detecting and tracking targets. The transfer function of an N-Line DLC is as follows-

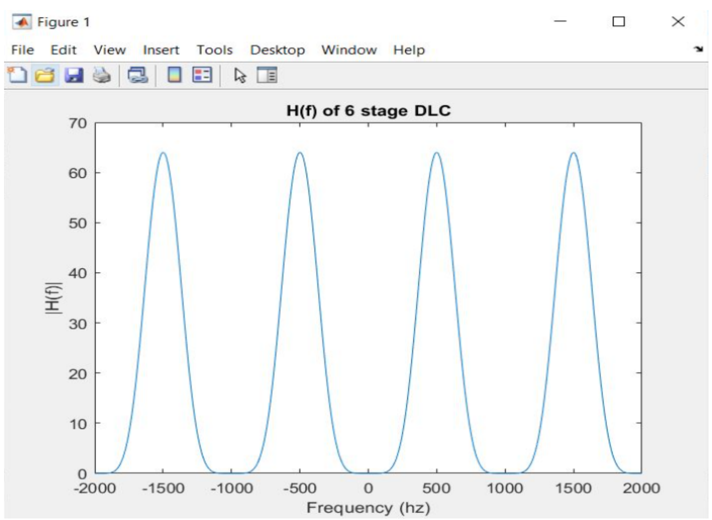
$$H(f) = 1 - \sum w(k) * \exp(-j2\pi f\tau(k))$$

Where H(f) =frequency response of the DLC,

w(k) = weight of the k^{th} delay element,

τ(k) = delay time of the k^{th} delay element,

f = frequency of the input signal.



Frequency response of 6-stage DLC

In General-

N -Line Delay Line Canceller = (N+1) pulse canceller

Example-

- Single Line Delay Line Canceller = 2 pulse canceller
- Double Line Delay Line Canceller = 3 pulse canceller

Frequency Response of Delay Line Canceler-

The signal from a target at range R_0 at the phase detector output can be written as.

$$V_1 = k \sin (2\pi f_d t - \Phi_0)$$

where f_d = Doppler frequency shift,

Φ_0 = constant phase equal to $4\pi R_0/\lambda$,

R_0 = range at time equal to zero,

λ= wavelength,

k= amplitude of the signal.

The signal from the previous radar transmission is similar, except a time T_p= pulse repetition interval delays it and is

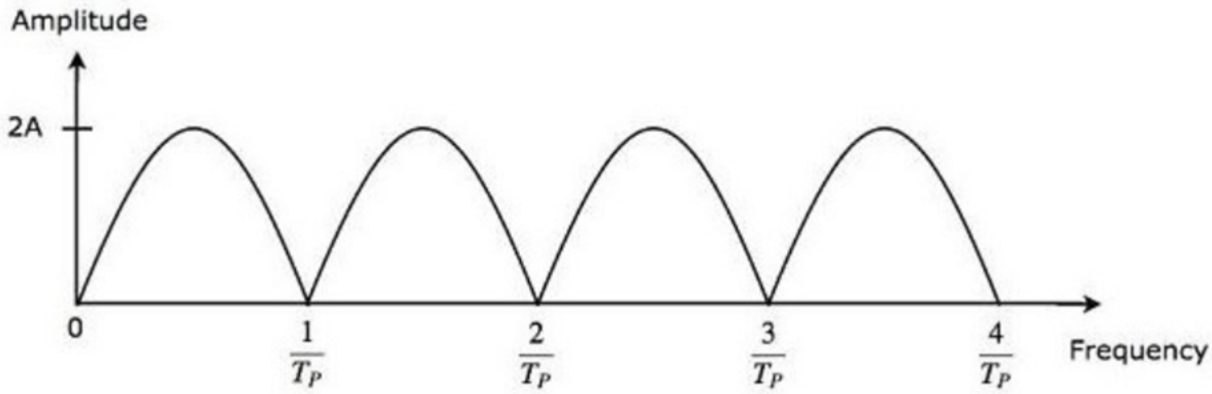
$$V_2 = k \sin [2\pi f_d (t - T_0) - \Phi_0]$$

Now, the delay line canceler subtracts these two signals

$$V = V_1 - V_2 = 2k \sin(\pi f_d T_p) \cos[2\pi f_d (t - T_p/2) - \Phi_0]$$

The output from the delay-line canceler consists of a cosine wave with the same frequency f as the input but with an amplitude of $2k\sin(\pi f_d T_p)$. Thus the amplitude of the canceled video output depends on the Doppler frequency shift and the pulse repetition period. The frequency response function of the single delay-line canceler (output amplitude divided by the input amplitude k) is then-

$$H(f) = 2\sin(\pi f_d T_p)$$



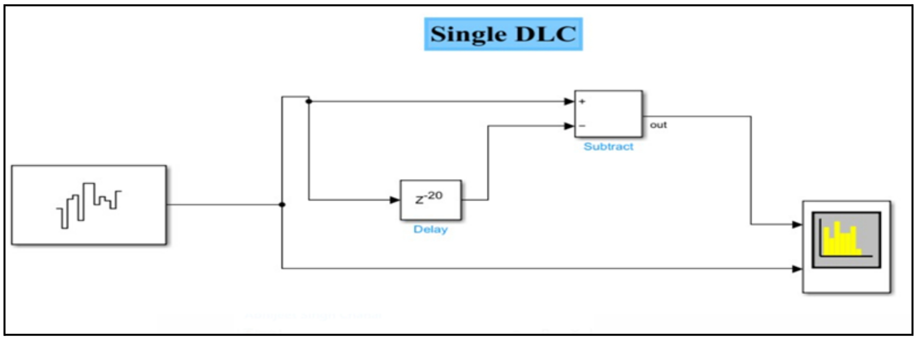
Two properties that can seriously limit the utility of this simple doppler filter:

(1) The frequency response function also has zero response when moving targets have doppler frequencies at the prf and its harmonics.

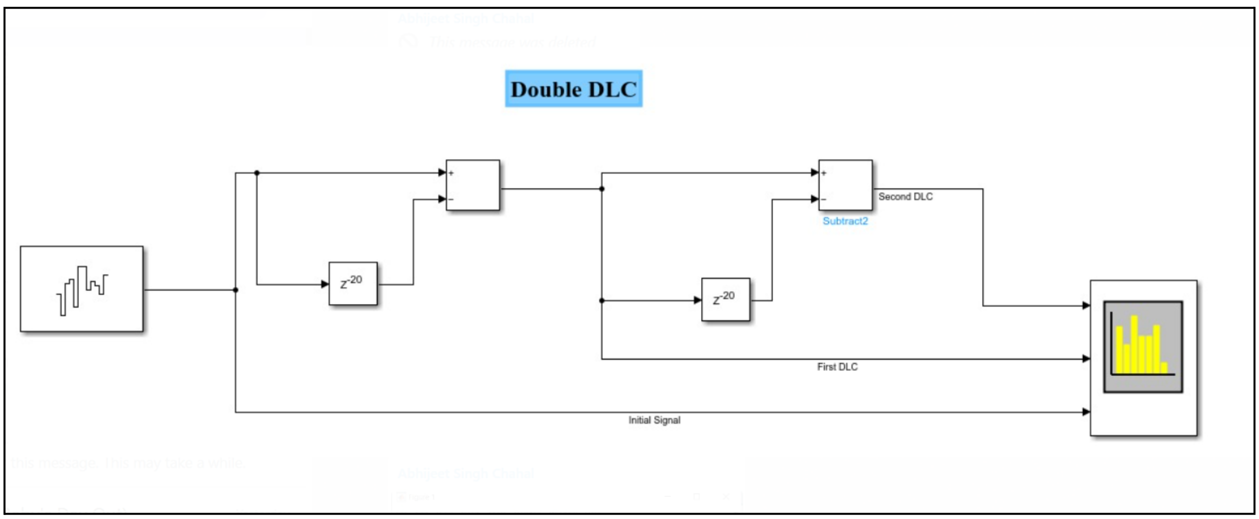
(2) The clutter spectrum at zero frequency is not a delta function of zero width but has a finite width so that clutter will appear in the pass band of the delay-line canceler. The result is that there will be target speeds called blind speeds, where the target will not be detected, and there will be an uncanceled clutter residue that can interfere with the detection of moving targets.

Layout/Circuit:

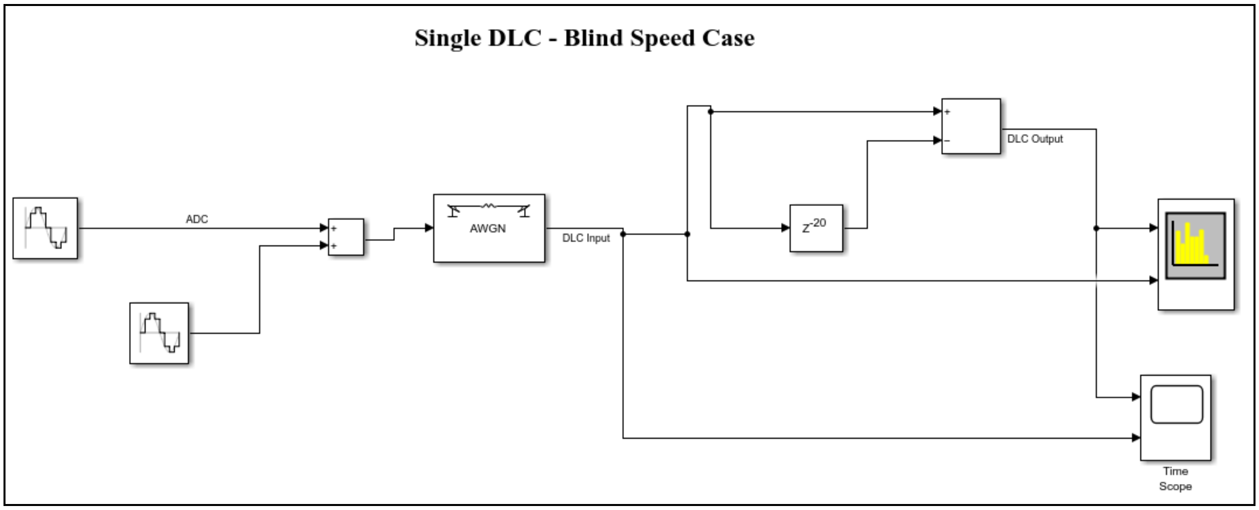
Given below are a few block diagrams showing the simulations performed:



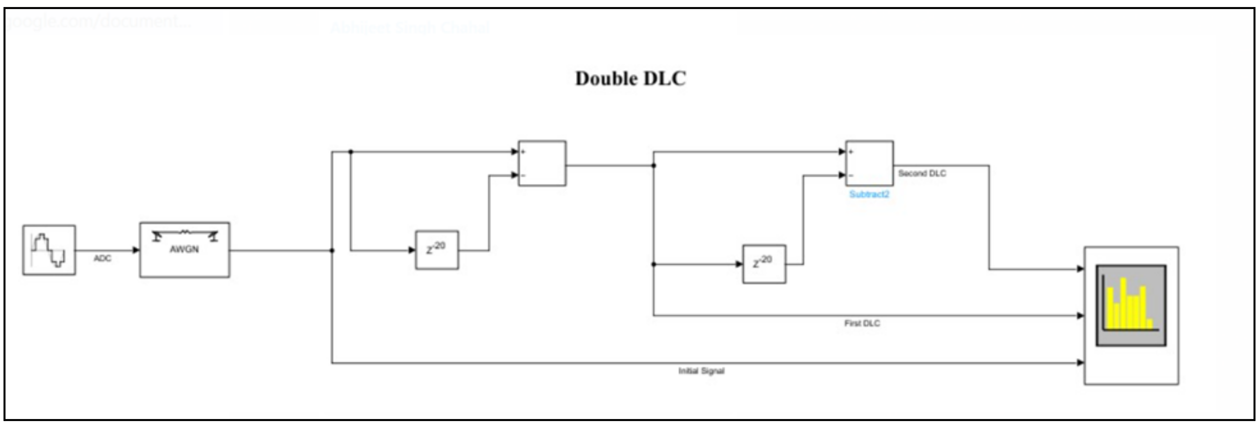
Single DLC response to AWGN channel



Double DLC response to AWGN channel



Single DLC -Blind Speed Simulation



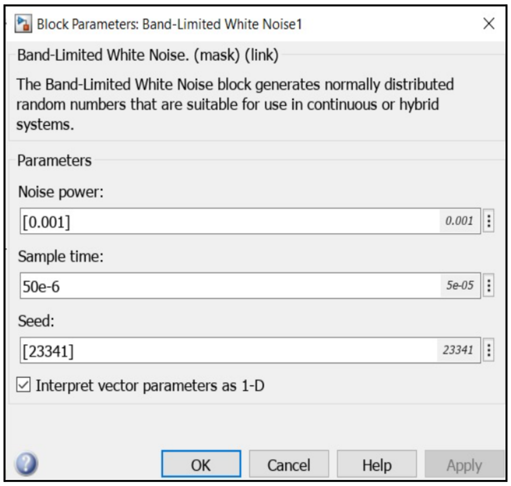
Double DLC response to a sinusoidal echo over an AWGN channel

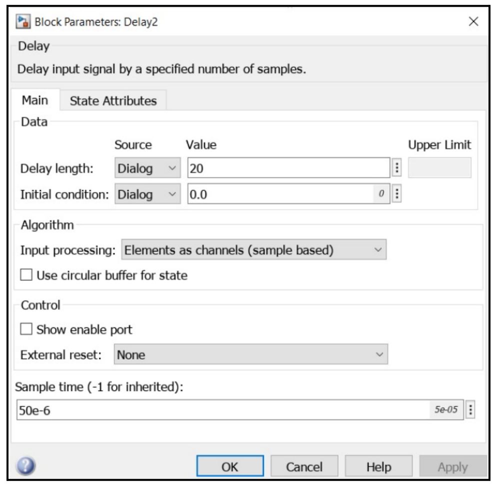
The first block diagram shows a DLC response to band-limited gaussian noise. It was simulated using a ‘Band-Limited White Noise’ block as the input. The ‘delay’ block was used to delay the incoming signal, and we used a ‘Spectrum Analyzer Tool’ block to plot the power spectral density of the output of the DLC.

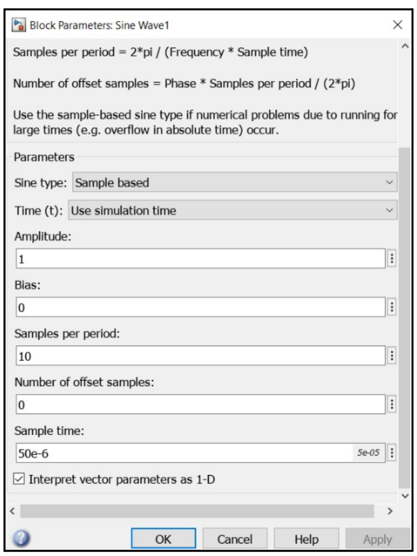
The third block diagram represents a sinusoidal echo received over a noisy channel. We used the ‘Sine Wave’ block and the ‘AWGN Channel’ block to achieve this.

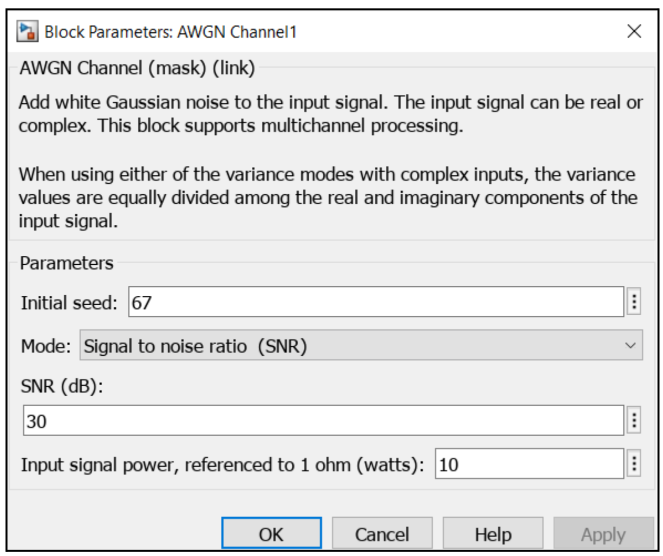
Calculation:

We gave the following parameters for the blocks:









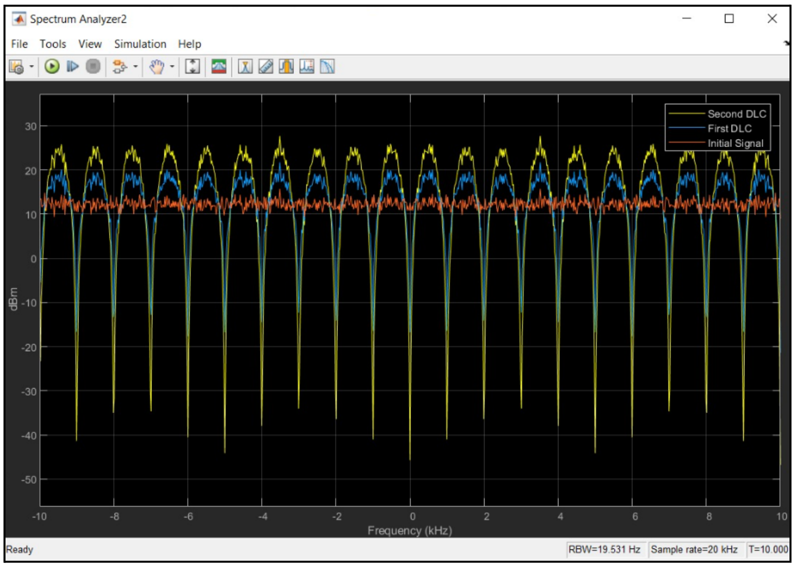
The sample time is the time between successive samples. MATLAB is a digital software and hence, we have to approximate analog signals using sampling.

The time between two samples is 5x10^{-5}s. Using this, we wanted to generate a delay signal of 0.001s, translating to a pulse repetition frequency of 1kHz. To do so, 20 samples of delay were added to the 'Delay' block

Working of Circuit and Components:

The following graphs were obtained while simulating the DLC on white gaussian noise:

Here, we took sample time as 50us and delayed length as 20.



DLC response with white gaussian noise

Let us look at an example to better understand the working of the DLC by demonstrating the working of our DLC on an MTI radar:

We shall consider the radar operating at the L-band frequency range operating at 1.3 Ghz frequency.

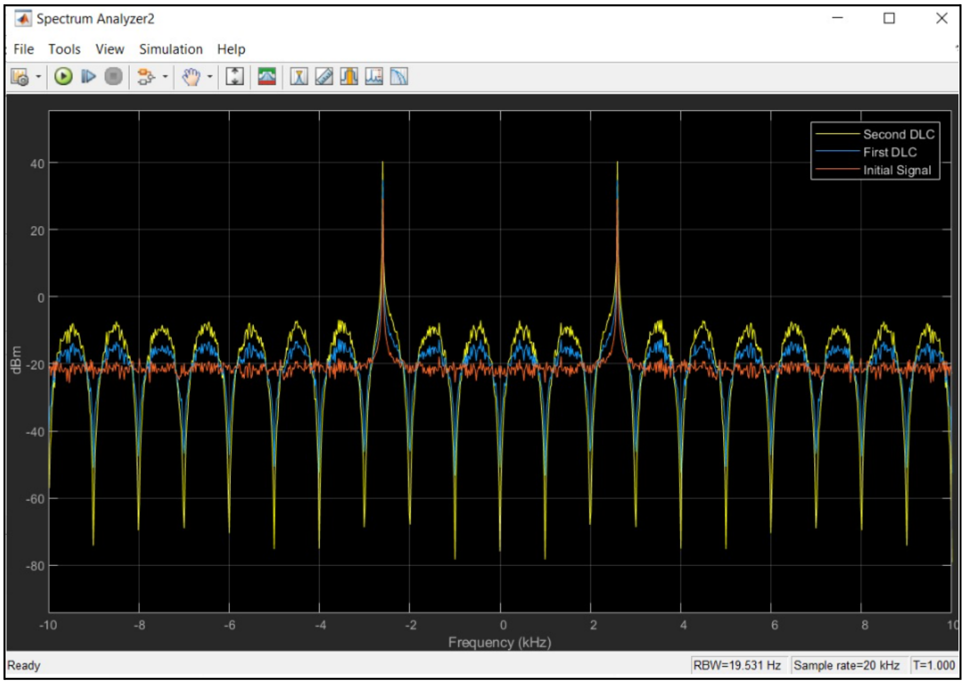
We are setting the pulse repetition frequency at **1000 Hz**.

∴ $\mathbf{R_{un} = c/2f_p}$

⇒ $\mathbf{f_c}$= $1.3*10^9$ Hz and $\mathbf{f_d}$= 2600Hz (received frequency)

Let us say it detects the target within this range, and the Doppler shift in the received echo is **2.6KHz**. We have the following observation from our DLC.

$\mathbf{f_d} = (1.3*10^9*\mathbf{v_r})/(3*10^8)$ ⇒ target is moving at **300m/sec**.



Echo response over a noisy channel

Thus, both the SDLC and the DDLC show a moving target over the spectrum

Blind Speed-

Blind Speeds- The response of the single delay-line canceler will be zero whenever the magnitude of $\sin(\pi f_d T_p)$ in the frequency response equation is zero, which occurs when $\pi f_d T_p = 0, \pm\pi, \pm 2\pi, \pm 3\pi$. Therefore,

$$f_d = 2v_r/\lambda = n/T_p = nf_p \qquad n=0,1,2\ldots\ldots$$

This states that in addition to the zero response at zero frequency, there will also be zero response of the delay-line canceler whenever the doppler frequency $f = 2v_r/\lambda$ is a multiple of the pulse repetition frequency f_p. The radial velocities that produce blind speeds are

$$V_n = n\lambda/2T_p = n\lambda f_p/2 \qquad n=1,2,3\ldots$$

In our example, let us add another target moving at a speed of 461m/s, translating to a frequency of 2kHz.

The following simulation results are observed:

Thus we see that the second target at 2kHz is hidden at blind speed

Clutter Attenuation-

Clutter attenuation refers to reducing or eliminating unwanted signals in radar systems, which can interfere with detecting the desired target signals. One way to accomplish this is by using the Moving Target Indication (MTI) radar.

The clutter spectrum refers to the frequency range of the clutter signals in the radar system. In the real world, the clutter spectrum has a finite width due to various factors such as the internal motions of the clutter itself (e.g., movement of leaves or branches in vegetation), the instabilities of the radar's local oscillators (such as the Stalo and Coho), imperfections in the radar hardware or signal processing algorithms, and the finite duration of the radar signal.

These factors can cause the clutter signals to have a frequency spread, meaning they occupy a range of frequencies rather than being confined to a single frequency. This can make it more challenging to distinguish the clutter signals from the signals of interest, such as those from a target, and can also reduce the overall sensitivity of the radar system. As a result, clutter attenuation techniques such as MTI radar can be used to effectively remove or suppress clutter signals and improve the accuracy of target detection.

For present purposes, we will assume the clutter power spectral density is represented by a Gaussian function and is written as.

$$W(f)=W_0 \exp(-f^2/2\sigma_c^2) = W_0 \exp(-f^2\lambda^2/8\sigma_v^2) \qquad f \geq 0$$

Where W_0 = peak value of the clutter power spectral density, at f=0, σ_c= standard deviation of clutter spectrum in hertz, σ_v= standard deviation of the clutter spectrum in meters/second.

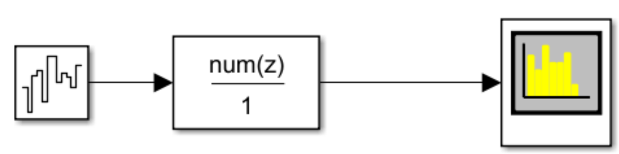
To simulate a clutter signal that is described by a gaussian power spectral density, we did the following:

1) Generate band-limited white noise
2) Filter it with a discrete gaussian filter

To create the gaussian filter, we ran the following code:

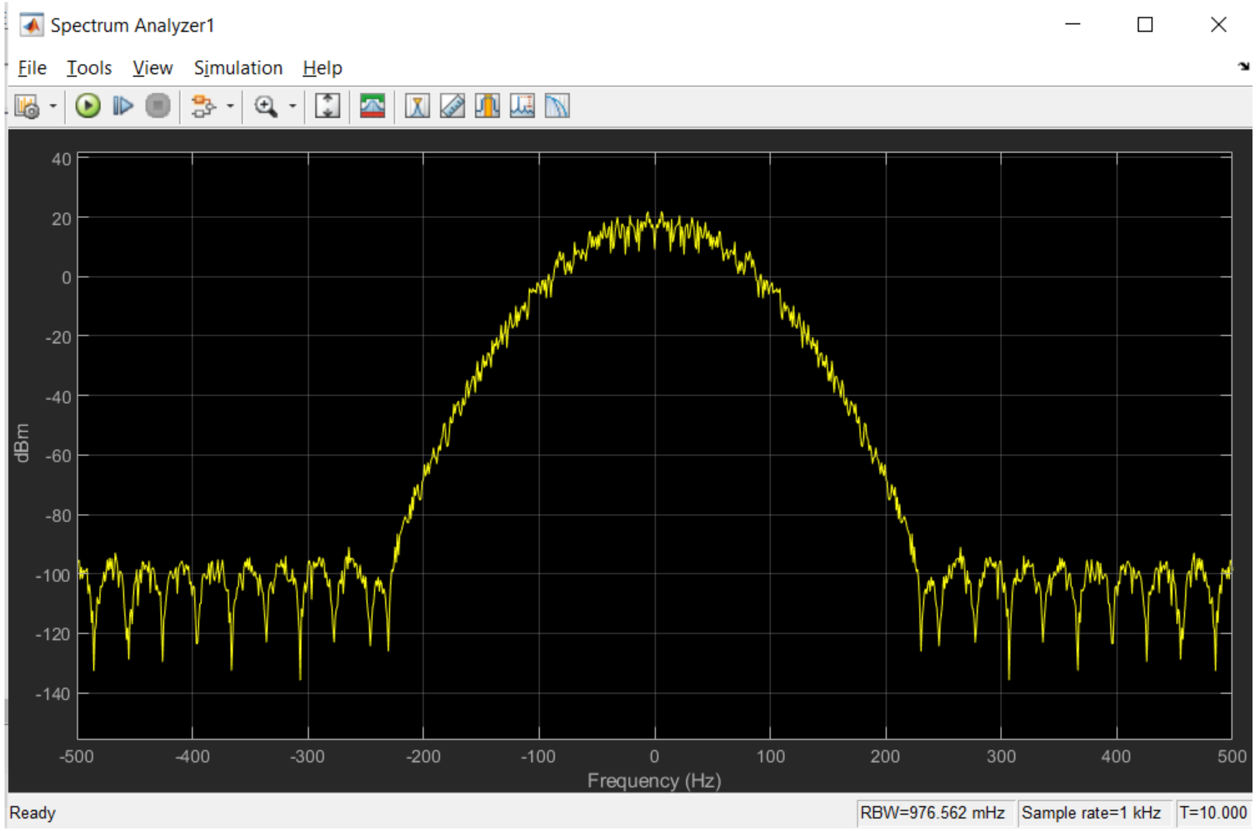
```
bt = 0.3;
span = 4;
sps = 8;
h = gaussdesign(bt,span,sps);
```

And then copied the filter coefficients generated in ‘h’ to the discrete FIR filter block.



Generation of clutter that has gaussian power spectral density

This gave us a clutter signal as follows:

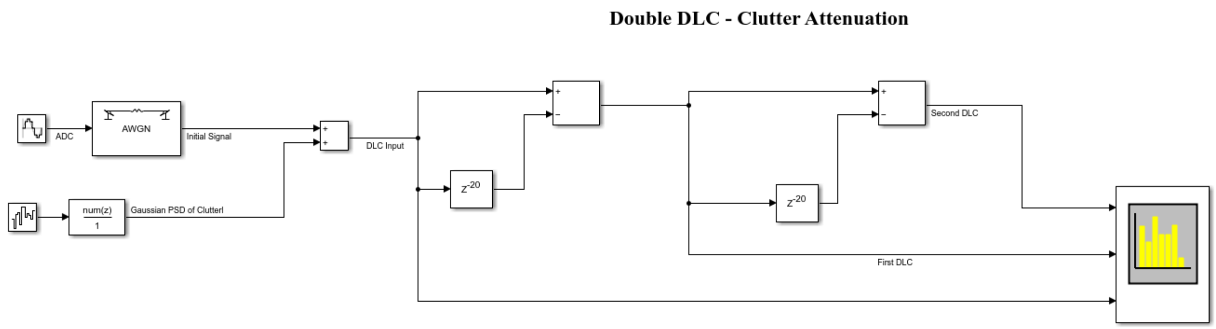


Comparison of simulated results with the desired parameter values:

Overall, we simulated the following real-world properties of the DLC:

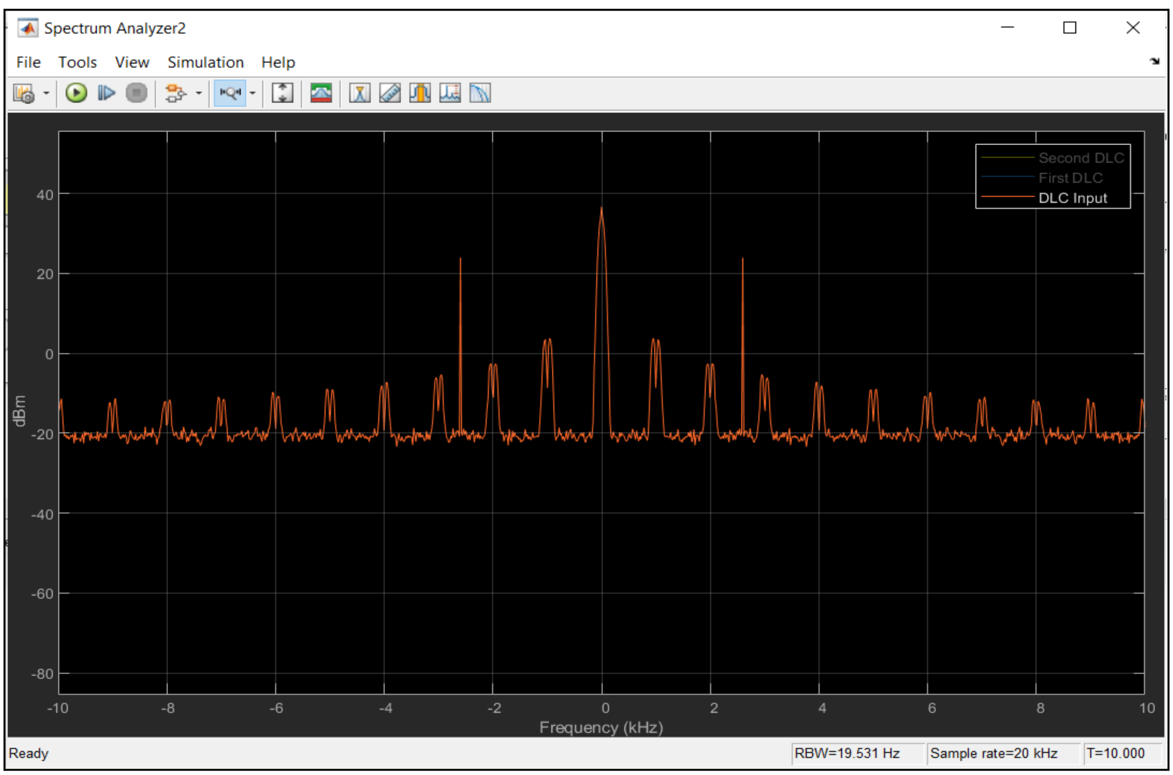
1) | H(f) | over white noise
2) Effect of moving target
3) Effect of blind speed
4) Clutter attenuation

Combining all the effects, we have the following final block diagram:

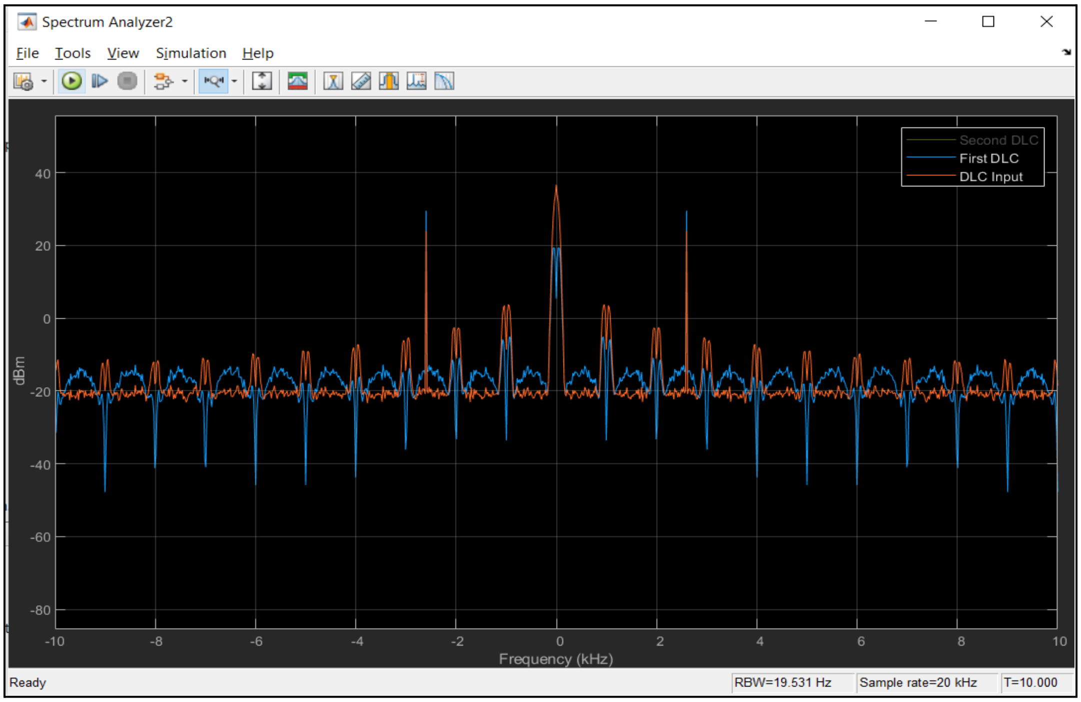


Double DLC with Clutter Attenuation

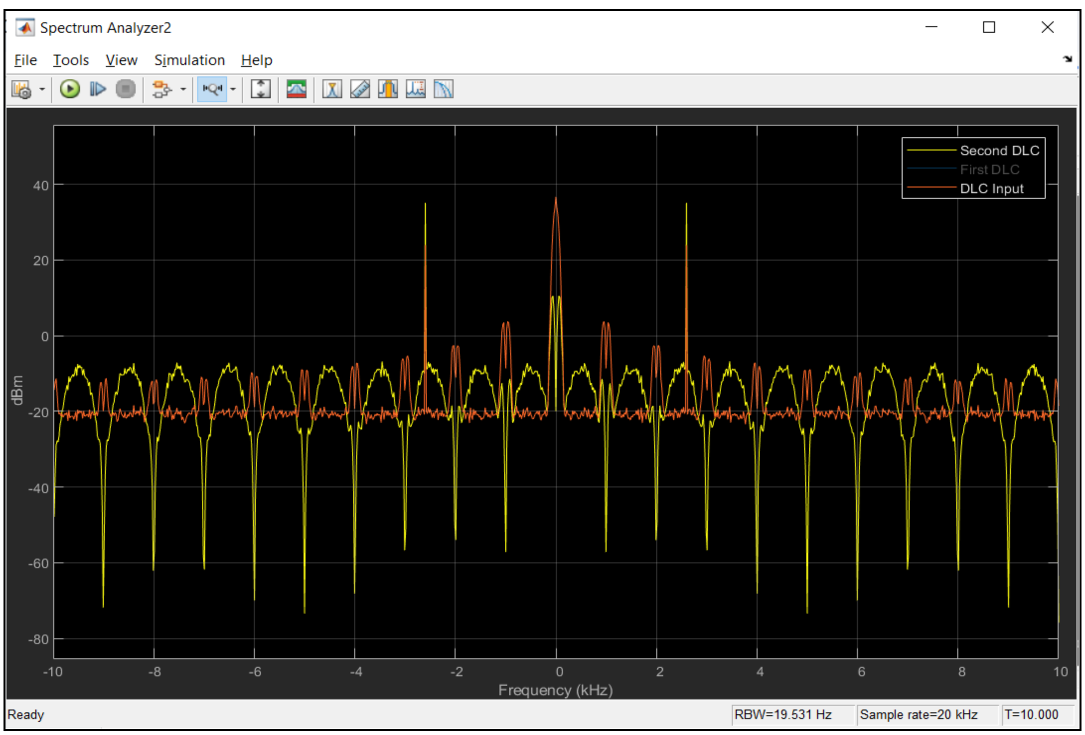
The input signal includes a sinusoid at 2600Hz, over an AWGN channel, along with a clutter signal added at 0, fp, 2fp and so on…



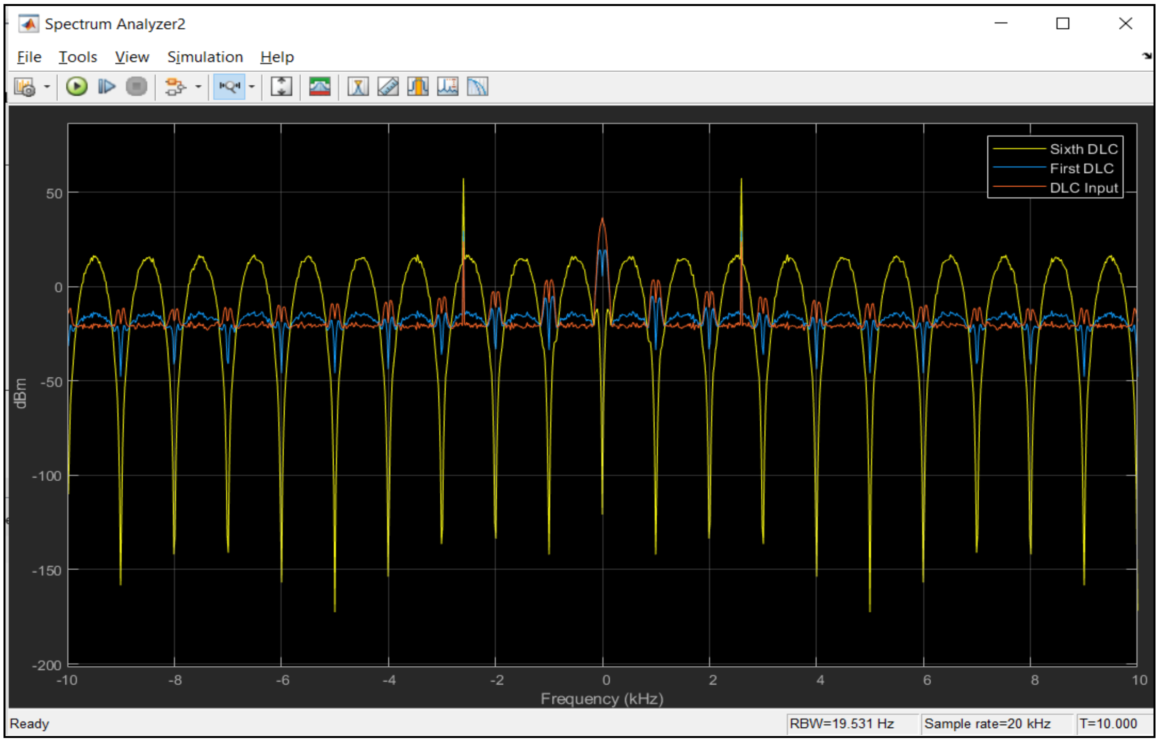
The following responses were obtained:



Response of Clutter Attenuation with First DLC



Response of Clutter Attenuation with Second DLC



Response of Clutter Attenuation with Sixth DLC

Thus, we still detect the target moving at 320m/s, and clutter has been attenuated. The double DLC gives better clutter attenuation than a single DLC. The higher the order, the better the attenuation; it is up to the designer to choose. We see that by increasing the stages in DLC, clutter attenuation can be done, but its cost is shrinking of pass band that increases missing of targets.

Conclusion:

In conclusion, Delay Line Cancellers (DLCs) are a powerful tool for removing unwanted clutter from radar signals. Through the use of Simulink simulations, we have seen the effectiveness of DLCs in attenuating clutter caused by an AWGN channel. Additionally, we have explored the impact of blind speed on the performance of DLCs and how different orders of DLCs can affect the clutter attenuation of the filter.

The results of our simulations demonstrate the importance of selecting the appropriate order of DLCs and tuning the blind speed for optimal performance. By utilizing DLCs, radar systems can achieve improved signal-to-noise ratios and enhanced detection capabilities. Overall, DLCs are an effective technique for clutter removal in radar systems, and further research into their implementation and optimization can lead to significant advancements in radar technology

Contribution of Individual:

Design and Simulation: Suresh Kaistha, Abhijeet Singh Chahal

Research and Project Report: Dushyant Singh Satyapal, Prashant Kumar, Ishanay Sharma

REFERENCES

1. Merril I. Skolnik, “Introduction to Radar Systems,” [Accessed: 12.Jan 2023]

2. Science Direct. Available: https://www.iist.ac.in/sites/default/files/people/IN14204/Lecture%2024-27-Pulse%20Radar-MTI.pdf [Accessed: Apr 15.Apr 2023]

3. TutorialsPoint. Available: https://www.tutorialspoint.com/radar_systems/radar_systems_mti_radar.htm [Accessed: Apr. 16, 2023]

4. Sreejith Hrishikesan, “Delay Line Canceler.” Available: https://www.electronicsandcommunications.com/2019/09/delay-line-canceller-block-diagram.html [Accessed: Apr. 21, 2023]

5. MATLAB, “Transfer Function in Simulink,” Jul. 15, 2015. Available: https://www.youtube.com/watch?v=rHuOEJbweIA [Accessed: Apr. 22, 2023]

6. Vincent Stevenson, “Transfer Function in Simulink,” Feb. 12, 2018. Available: https://www.youtube.com/watch?v=Eu97yx740PM [Accessed: Apr 22, 2023]

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