ADVANCED DIGITAL SIGNAL PROCESSING(ELL-720)

<u>ASSIGNMENT – I</u>

Range and axial velocity profile estimation using correlation processing and end-point detection methods

<u>SUBMITTED TO:</u>

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<u>Submitted by:</u>

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Introduction

We have data collected from a radar system, comprising 21 incidentally received pulses after striking a target. Each pulse was sampled 500 times at a rate of 20 M samples/sec. These pulses were transmitted as chirped pulses with a duration of 10 microseconds. Our objective is to utilize two algorithms, Correlation Processing and End Point Detection, on this data. The aim is to determine the range (distance) and velocity profile (speed) of the moving target detected by the radar.

We'll figure out the target's distance in millimeters using one of the methods mentioned earlier. This involves using Z, where each number represents a distance corresponding to a point in the radar data. By matching up the point in the data with the number in Z, we can find the target's distance in millimeters.

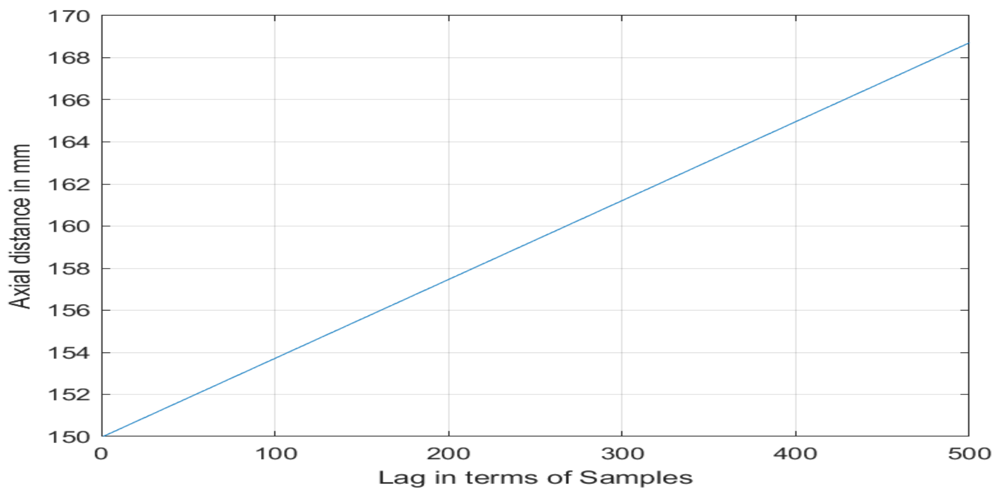


Fig 1. Variation of Z with different starting point of received Pulse

To calculate the speed of the ultrasonic wave, we first establish that the slope is 0.0375 mm/sample, and the sampling frequency is fs = 20 Msamples /second. The sampling period, T, is 1/f, which equals 0.05 µs. This means that for every one-sample lag (0.05 µs), the target's distance increases by 0.0375 mm.

So, the velocity of ultrasonic wave in water is:

$$v = \frac{2d}{T}$$

Here: d represents the distance corresponding to each sample lag, which is 0.0375 mm.
T is the sampling period or corresponding lag time, which is 0.05 µs.

Plugging in the values, we get: $v = \frac{2*0.0375*10-3}{0.05*10-6}$

So speed of ultrasonic wave is 1500 m/s.

Correlation Processing

To implement the correlation processing method, we begin by using a reference pulse, which is a linearly chirped pulse with a frequency ranging from 1.5MHz to 4.5MHz in our scenario. This reference pulse is correlated with the received echo pulse. The correlation process yields a result that includes the maximum value and the corresponding index value subtracts 500, represents lag.

To calculate the distance

$$Distance = \frac{lag * 1500}{2 * sampling\ frequency} + 0.150\ meters$$

This formula accounts for the time delay (lag) in the ultrasound signal. To convert the result into millimeters, we multiplied it by 1000. Additionally, we added 150mm to the result to accommodate the initial distance of 150mm from the target when the echoes begin.

The formula used to calculate velocity (v) is given by:

$$v = \frac{difference\ in\ consecutive\ distances\ of\ measurements}{timestamp(2) - timestamp(1)}$$

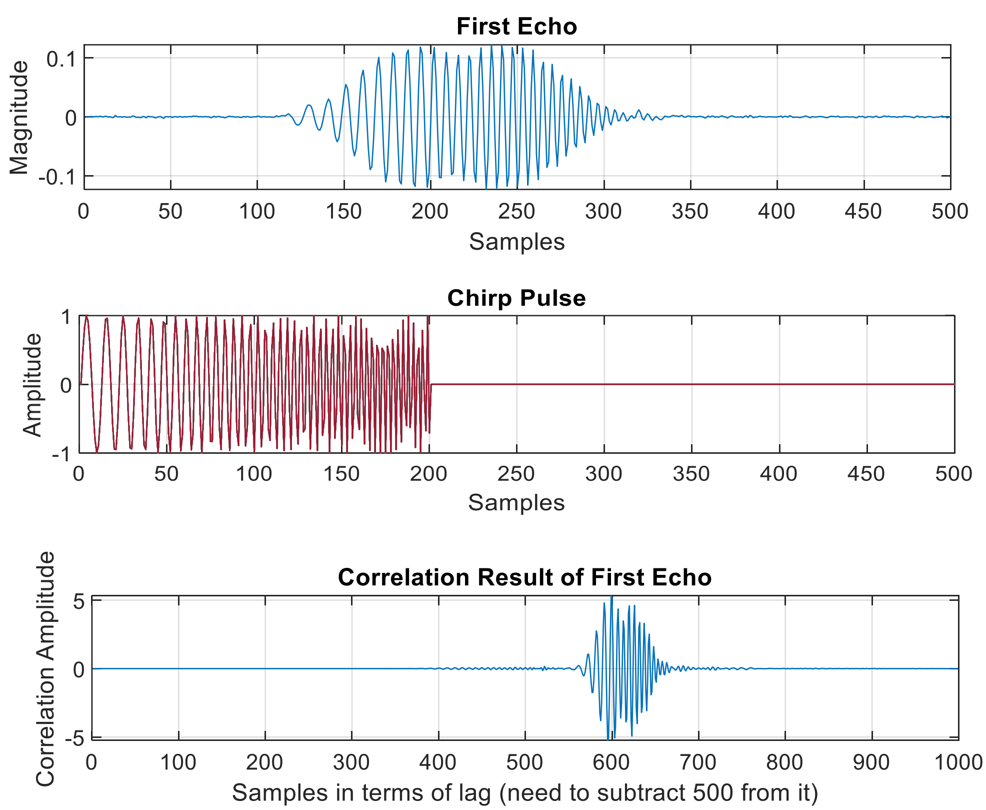


Fig2. Correlation Processing for one of the Received pulses

By figure 2 of correlation result it seems that to get lag value we have to subtract 500 from sample value.

Results :

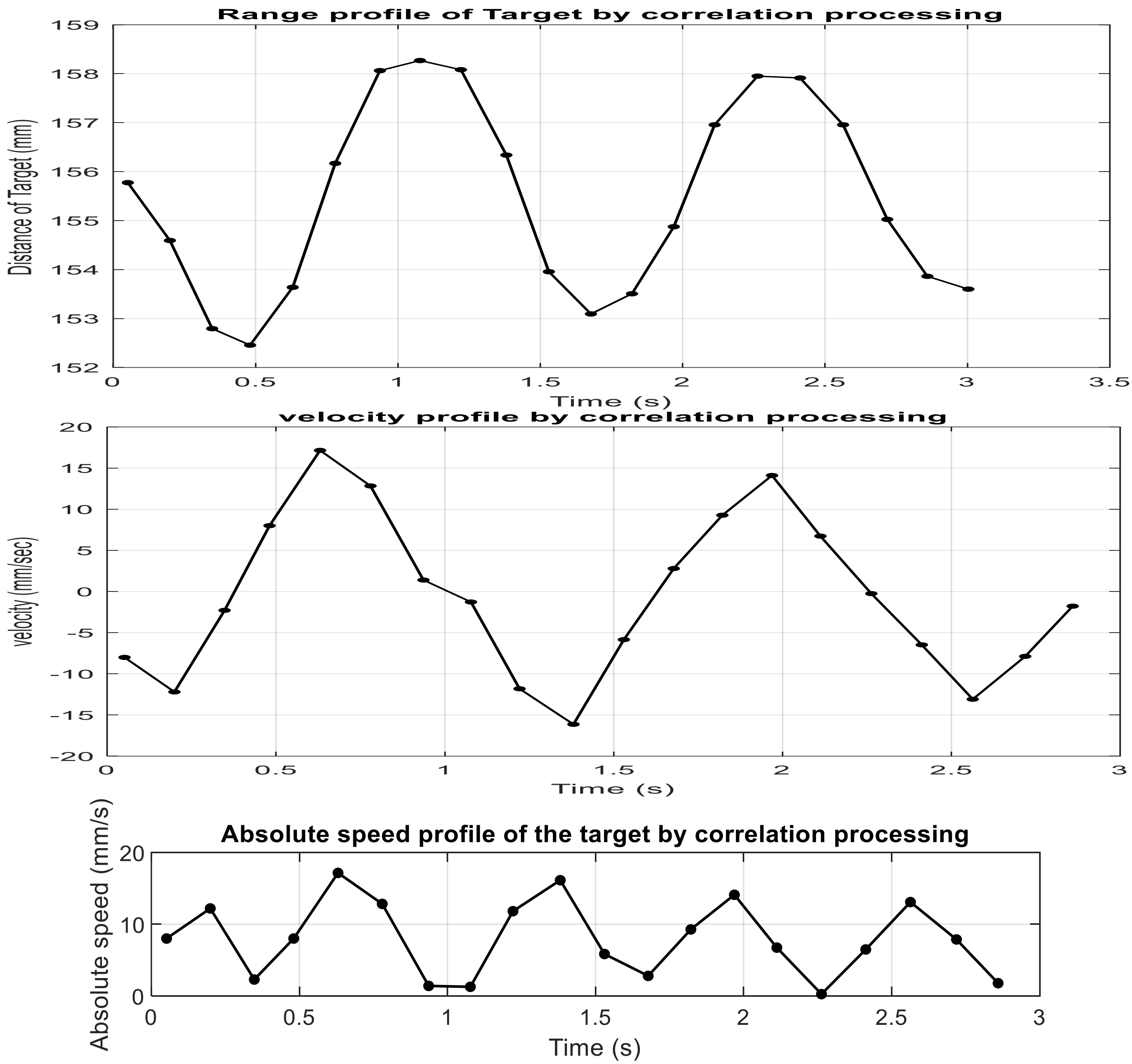


Fig 3. Result of correlation processing

End Point Detection

We determined the start index for the first echo using a threshold-based method.

$$E=\sum_{i=i}^{no}|x[n]|^2$$

So mean energy = $E/500$

Here 500 is samples, now threshold is given as a scale factor α times mean energy

For determining the scale factor α in our case we found signal energies corresponding to starting points(samples) as determined by correlation processing, from set of those 21 values we chose the max value, so optimum α = 1.1 which yields results similar to correlation processing. For signals with added noise, we may have to try with hit and trial to find optimum value.

The start index was then found as the first index where the absolute square of the RF data exceeded this threshold. This index represents the lag in the ultrasound signal.

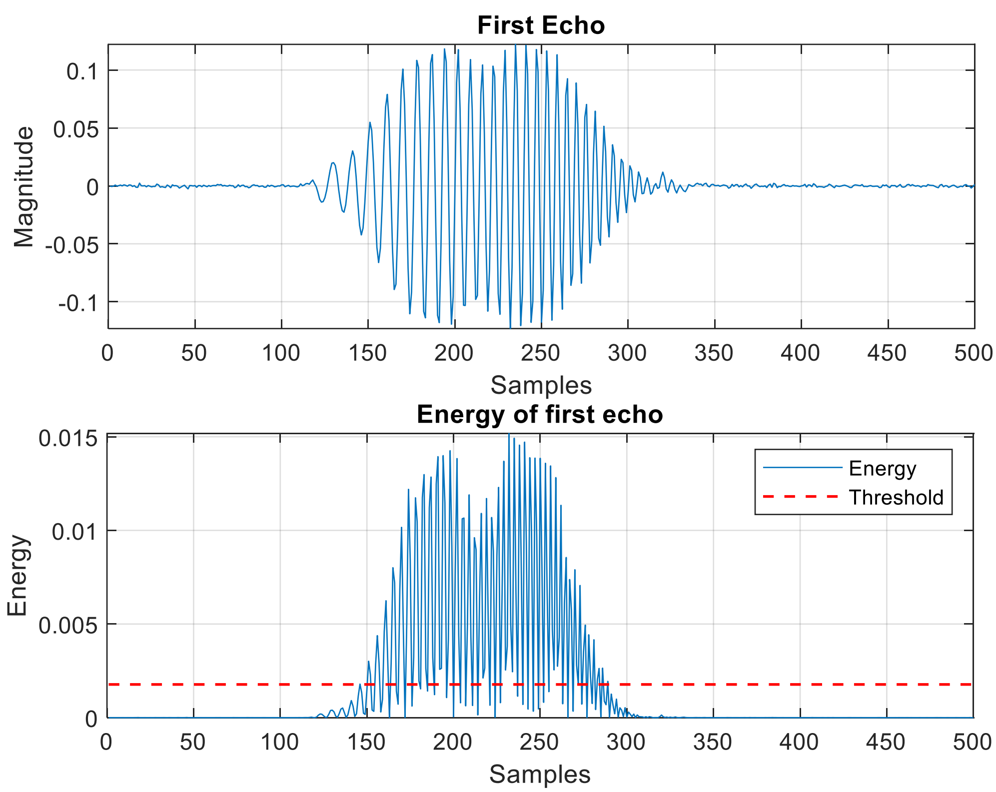


Fig 4. End Point detection based on energy plot for first received pulse

Results:

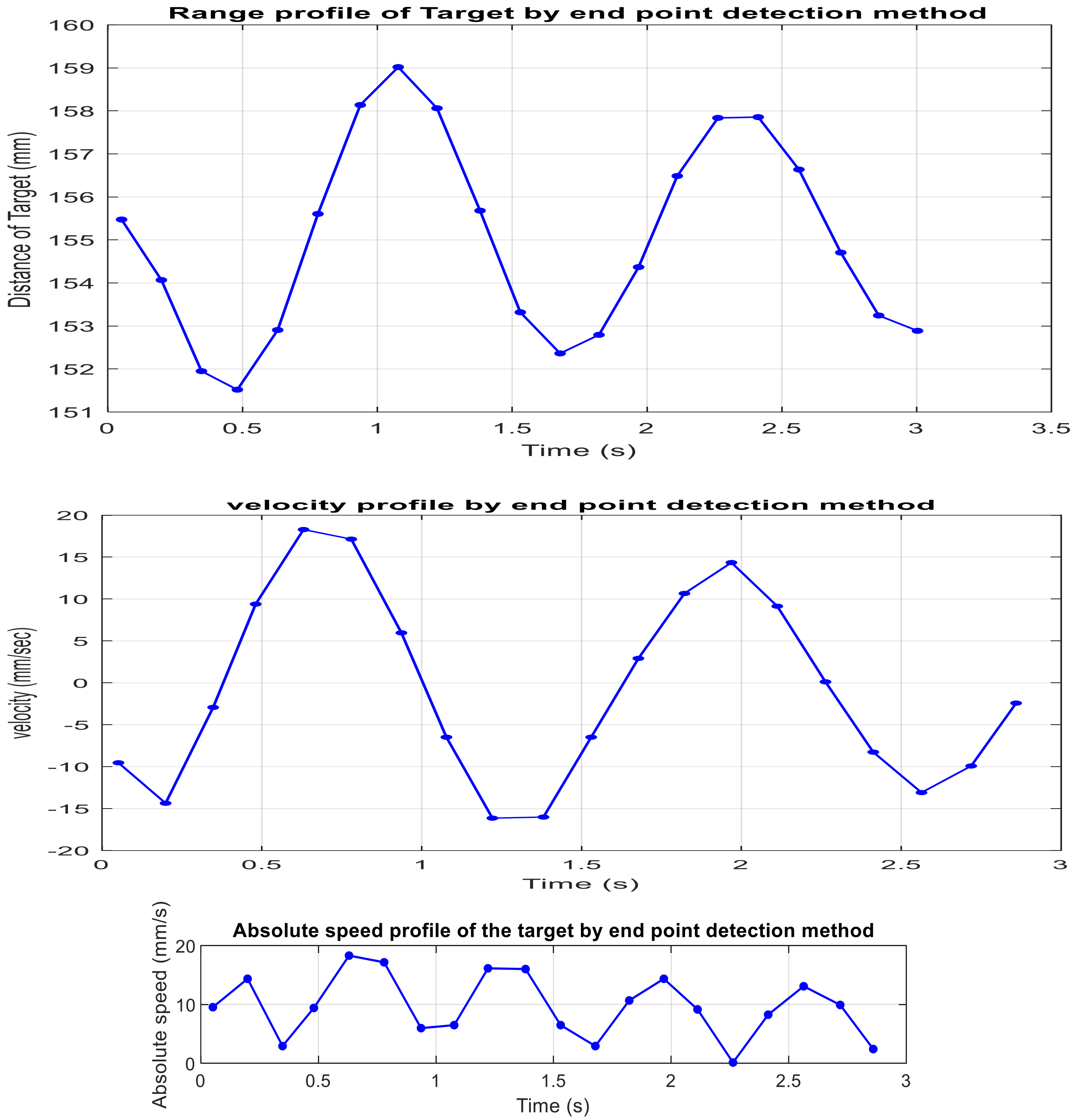


Fig5.Results of end-point detection method

Comparison of both methods:

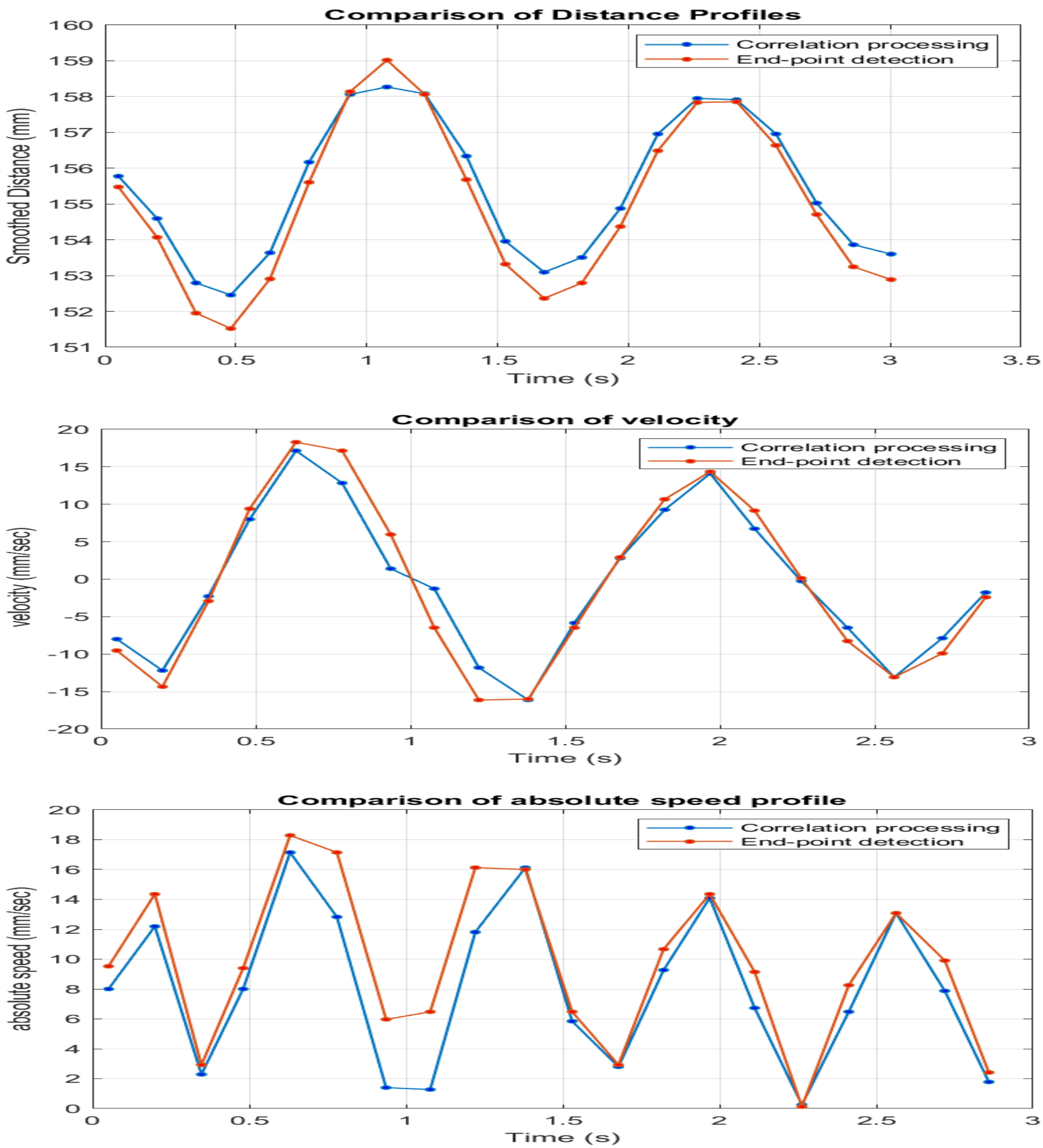
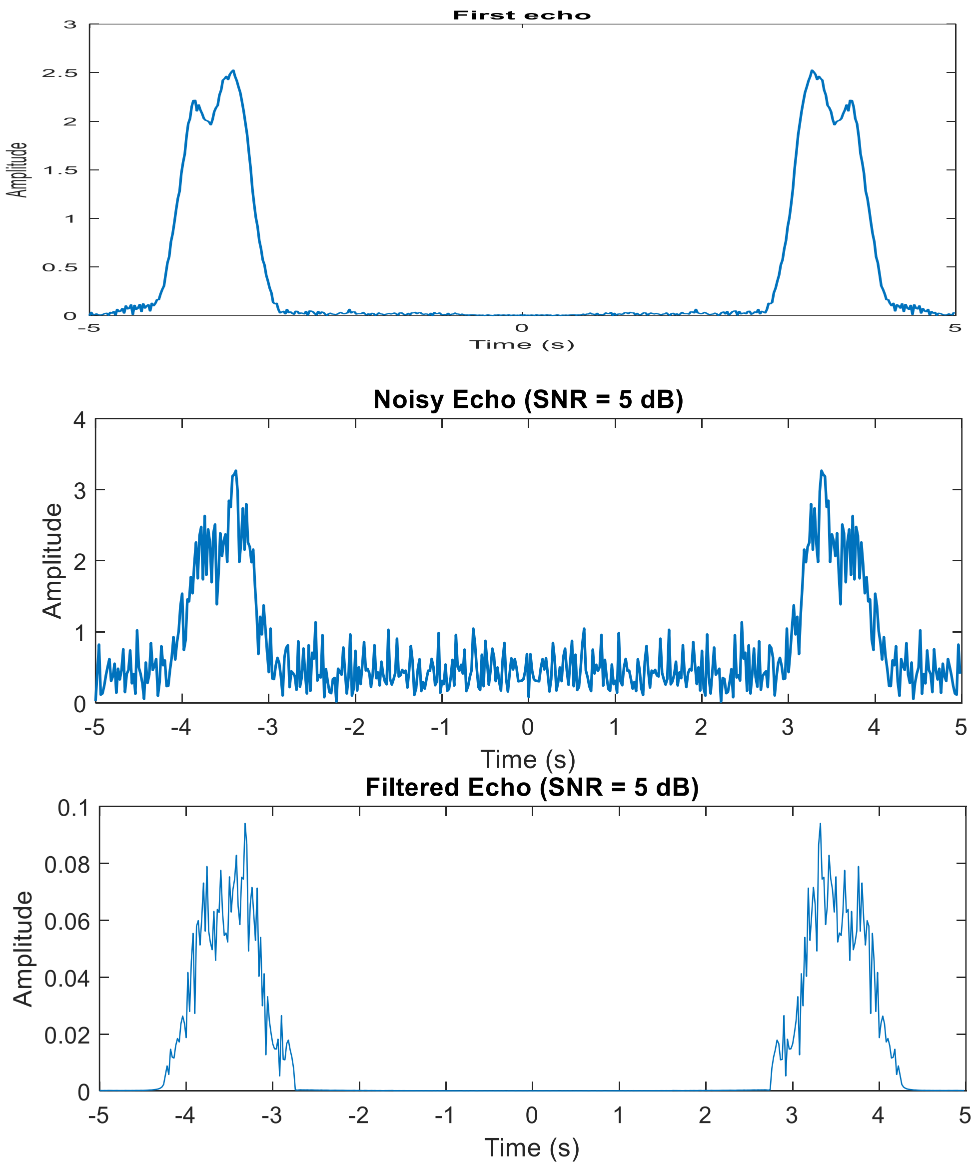
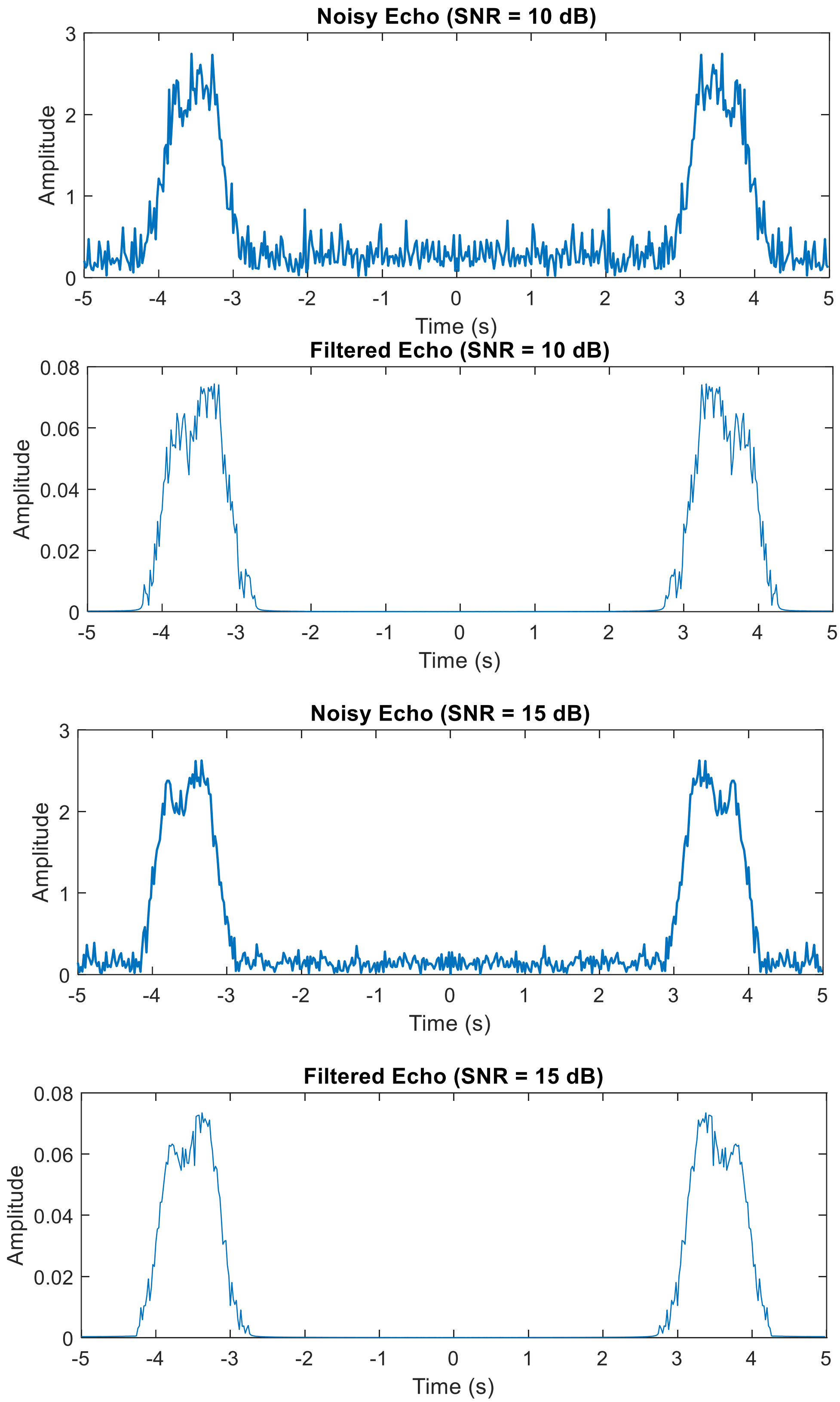


Fig6. Comparison of correlation processing and end-point detection method

Effect of adding Noise and pre-filtering

To see that effect of Noise that maybe to added to pulse at different stages, we can add additive white gaussian noise of different SNR i.e. 5dB,10dB,15dB,30dB to the samples and see the corresponding effect, for this purpose frequency domain representation of one of received pulse and same pulse with added noise having different SNR of 5dB,10dB,15dB,30dB has been shown in fig. Here we can see the received signal is also band limited and chirped. To eliminate the effect of Noise, we have designed a bandpass filter in Matlab to suppress noise outside signalbandwidth, whose gain and phase response has been shown in figure8. After passing the pulse through the filter the noise components would be suppressed, whoseeffect can be seen in figure 7.





Noisy Echo (SNR = 10 dB)
Amplitude
Time (s)
Filtered Echo (SNR = 10 dB)
Amplitude
Time (s)
Noisy Echo (SNR = 15 dB)
Amplitude
Time (s)
Filtered Echo (SNR = 15 dB)
Amplitude
Time (s)

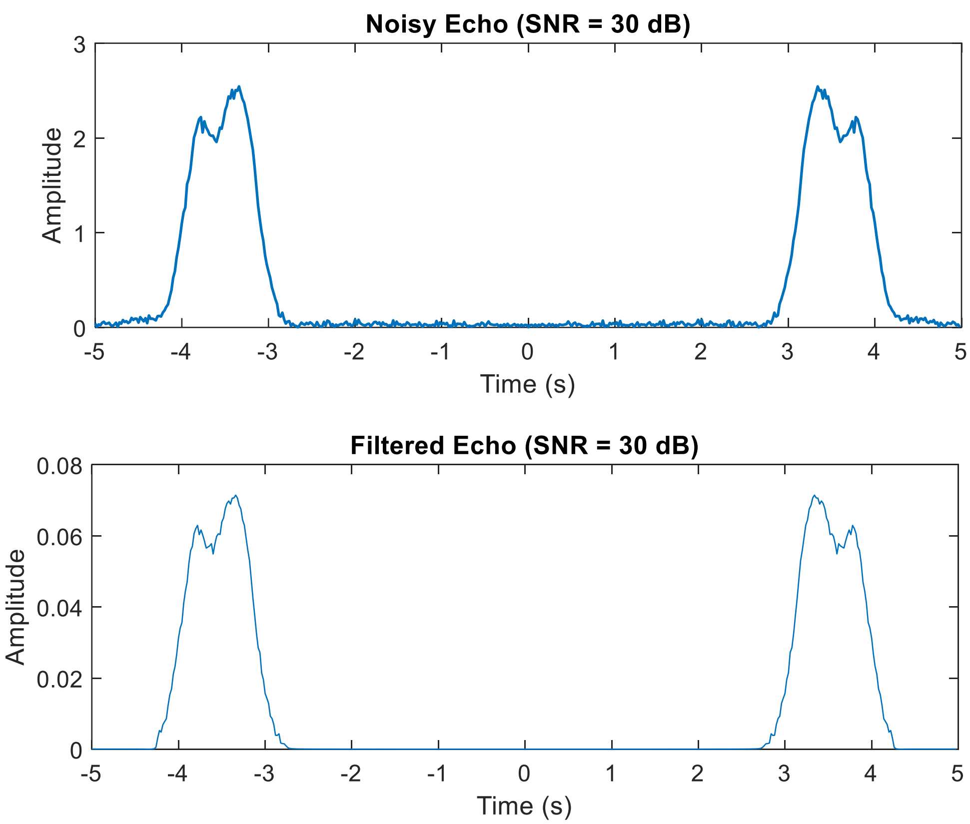


Fig 7. Frequency spectrum of a received signal with noise and after filter

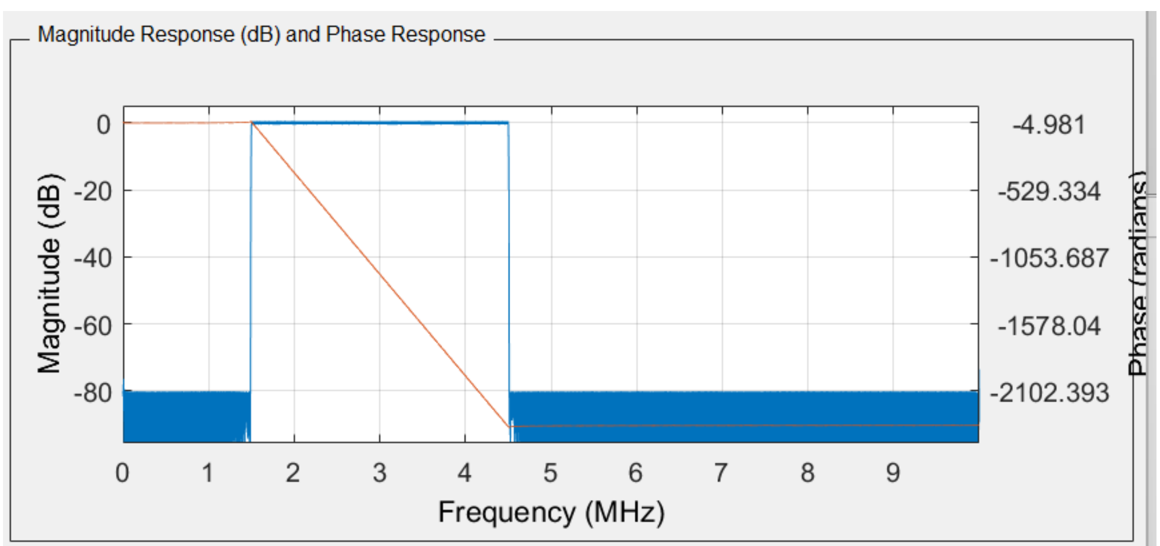


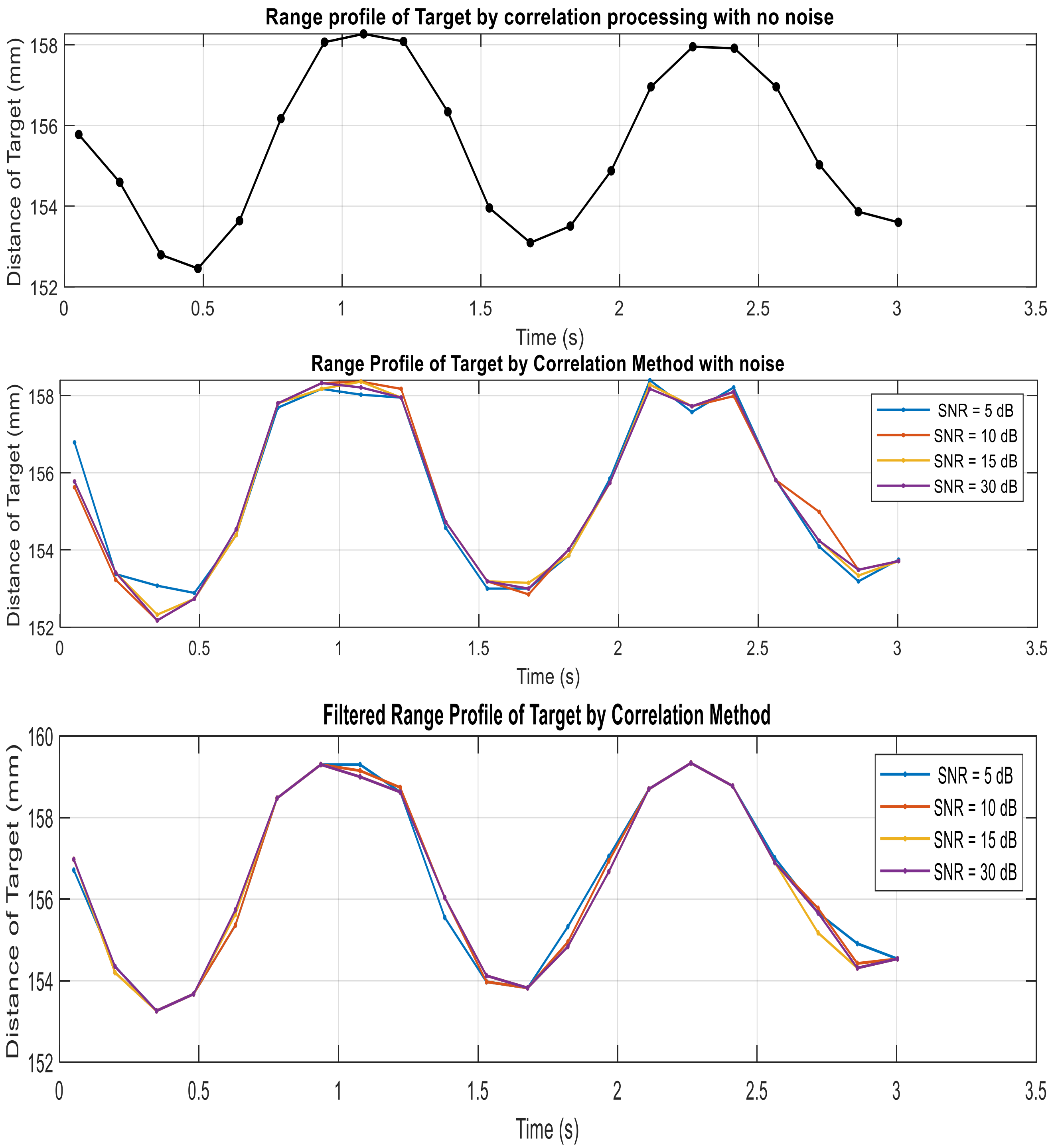
Fig 8. Band pass filter magnitude and phase response

Filter eliminated all the noise components outside the signal bandwidth, but filter also has its linear phase response as shown in fig 8.

$\partial\omega$

Correlation Processing in presence of Noise and after applying Filter

Signal with AWGN having SNR of 5dB,10dB,15dB,30dB have almost no much effect on distance calculation of distance as correlation peak occurs at almost same Point, as can be seen in fig. 12



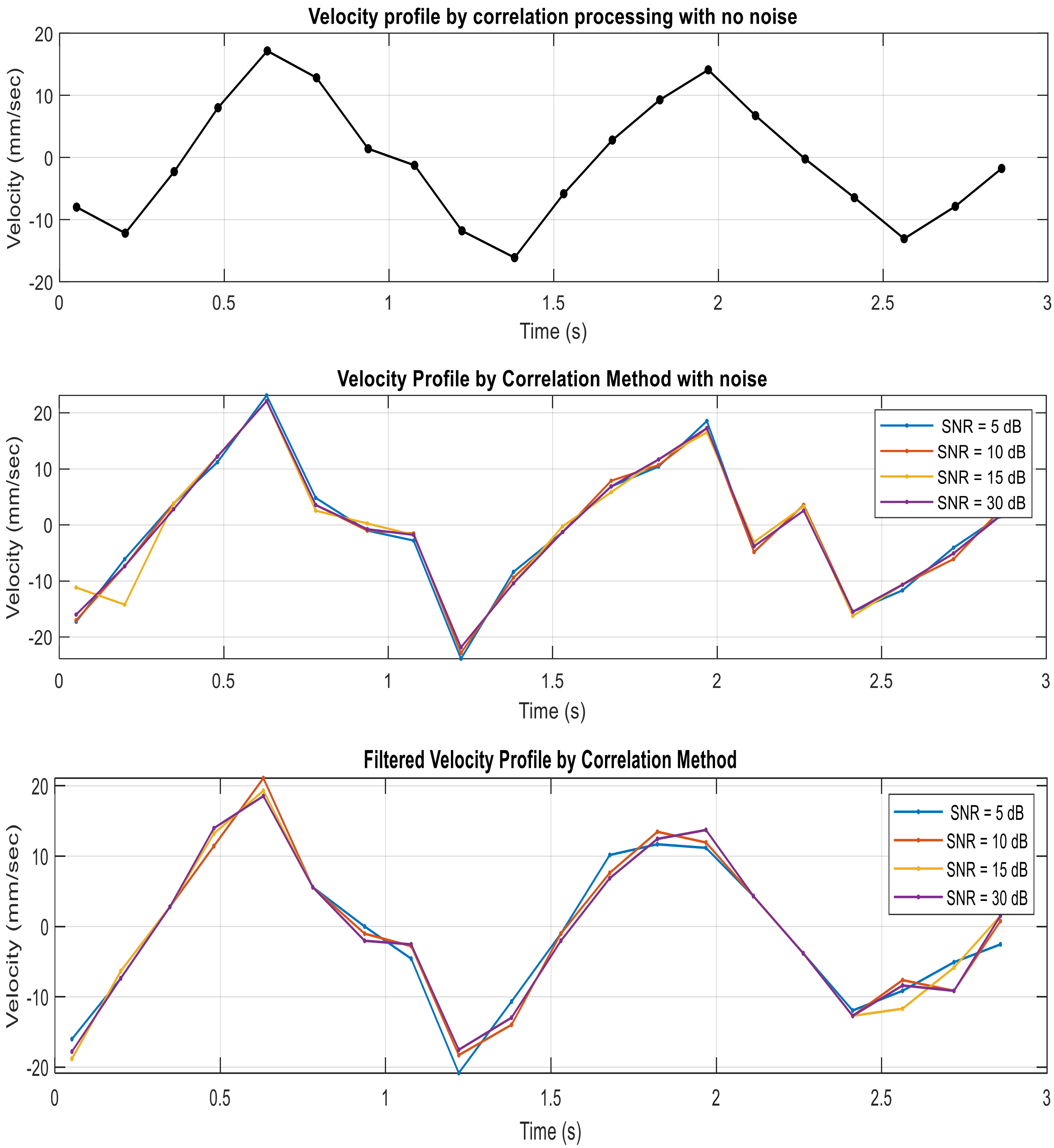


Fig 9. Effect of AWGN on Correlation Processing

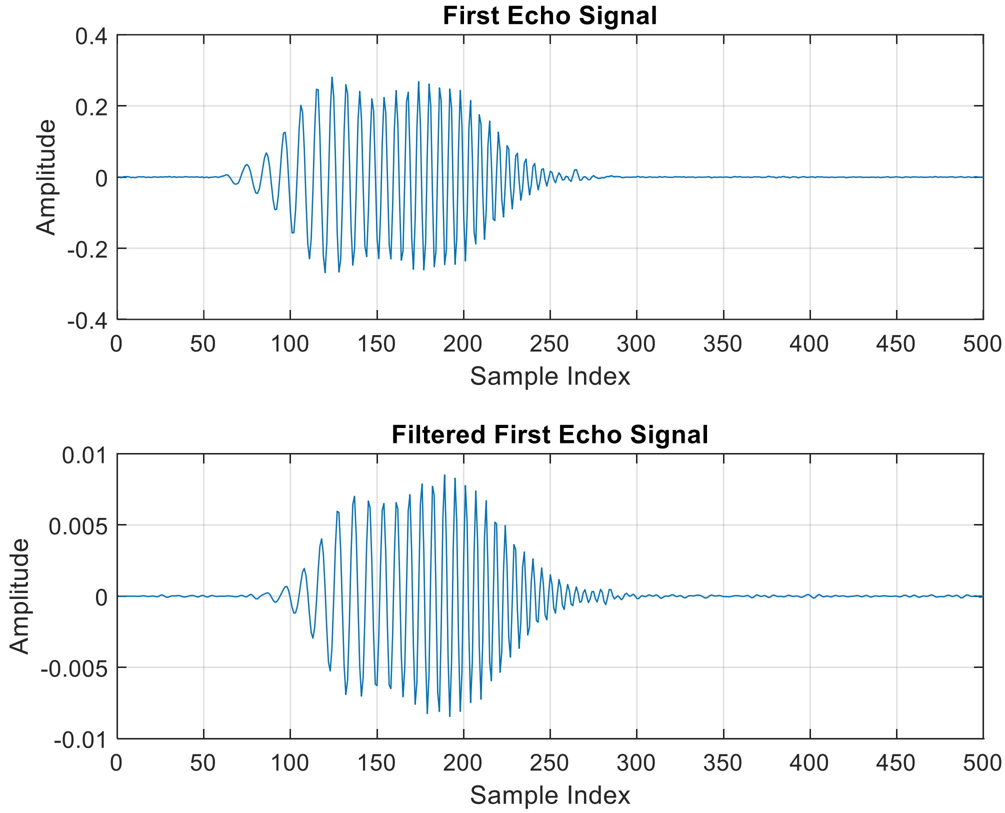
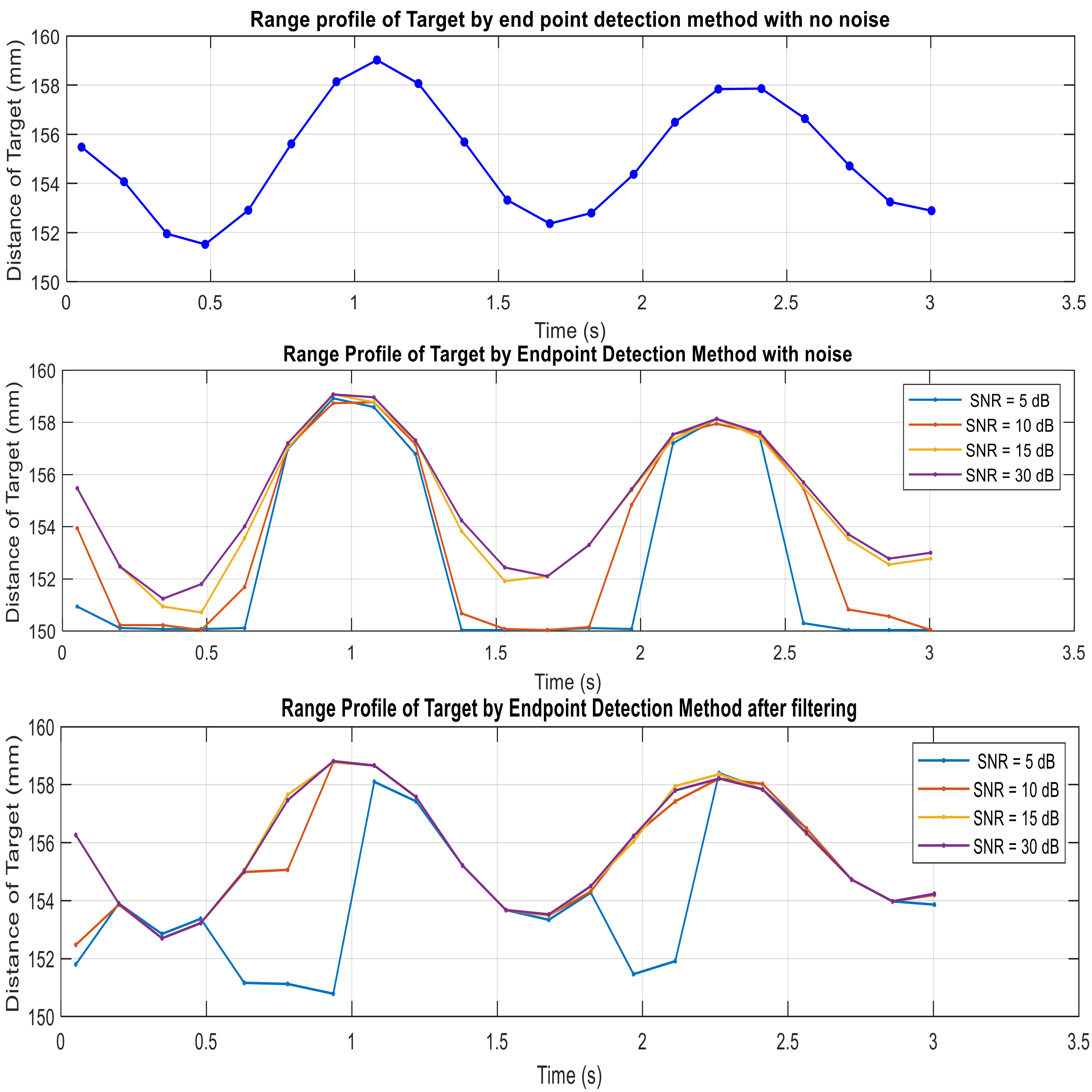


Fig 10. Effect of filter on first echo

Here we can infer that the filter has added a delay in the echo pulse, which means the shape of the distance profile we can accurately get, but due to the delay, the distance profile gets shifted on the distance axis.

End Point detection in presence of Noise and after applying Filter

Now the Threshold energy level will change, we can detect starting point wrongly in presence of AWGN, SNR of signal at 5dB,10dB,15dB,30dB a sample plot ofdistance profile and velocity profile shown in figure 10.



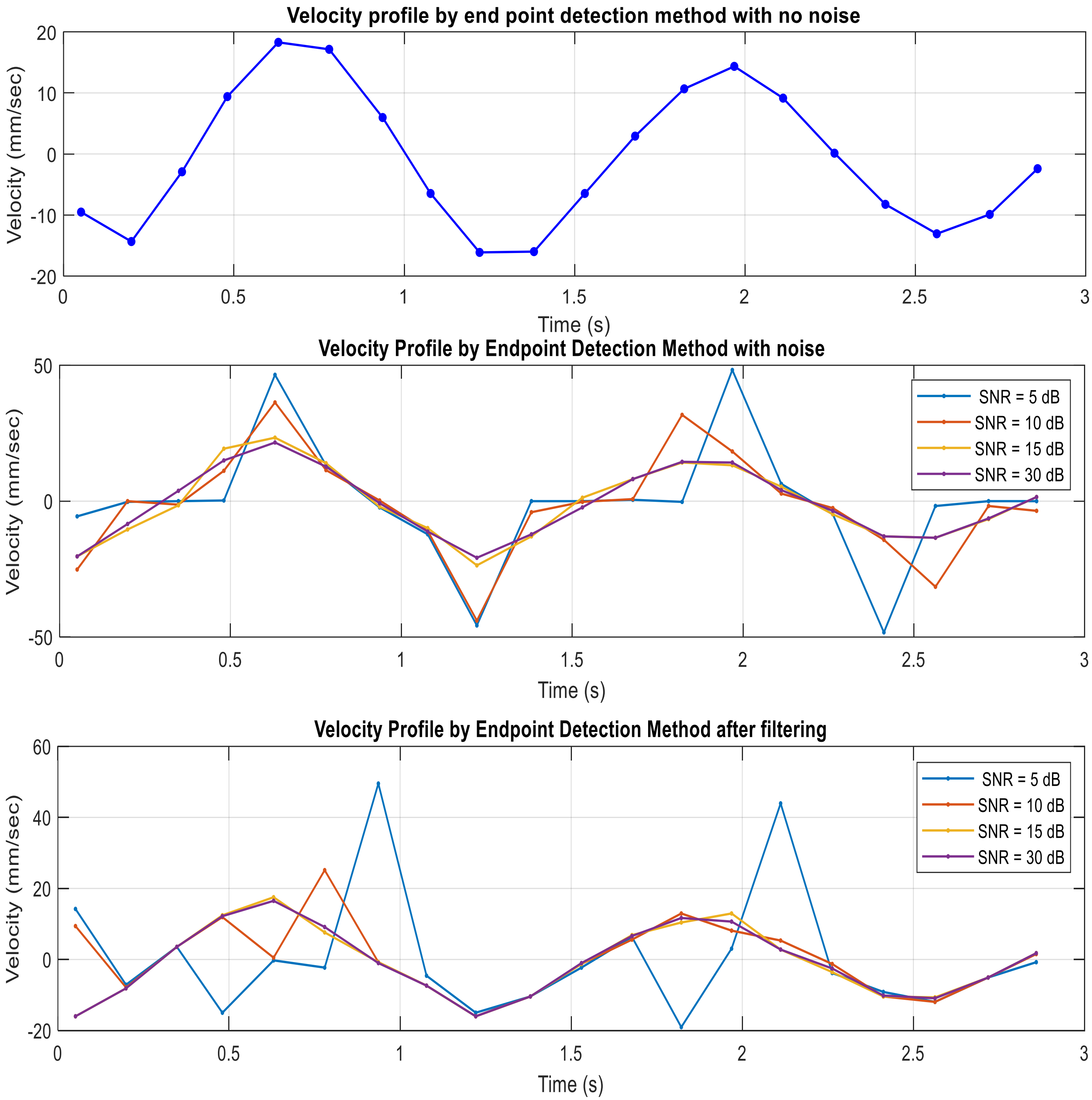


Fig 11. Effect of Noise on distance and velocity profile using End Point Detection Method

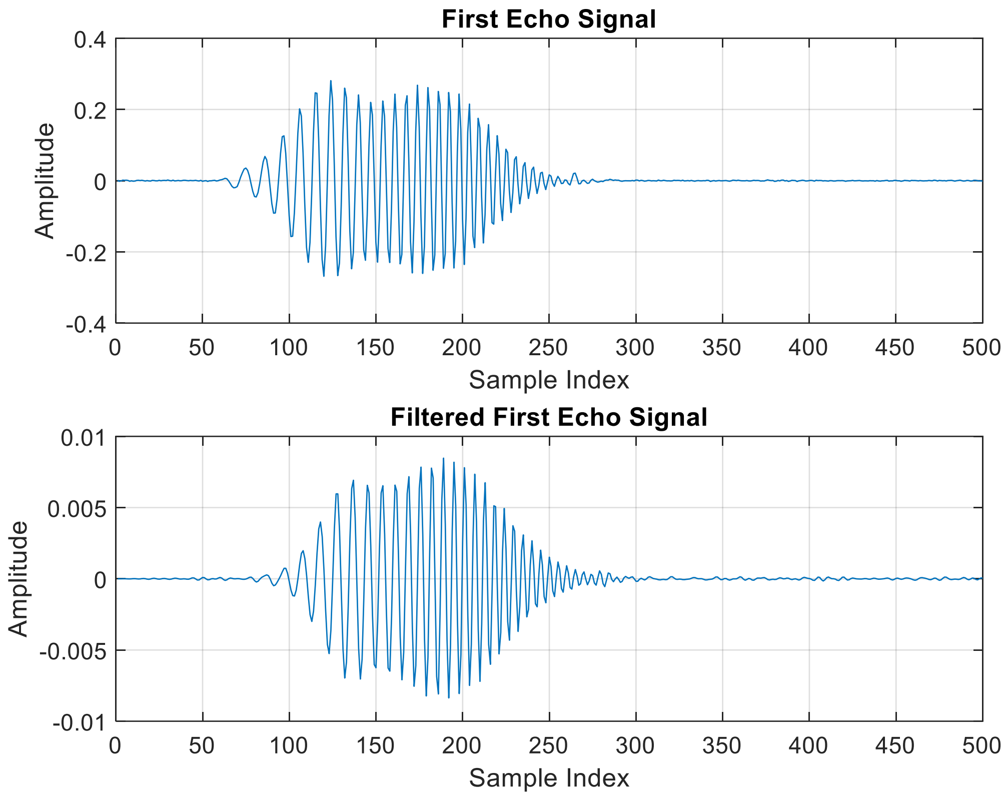


Fig 12. Effect of filter on first echo

We can clearly observe due to noise distance profile is inaccurate for 5dB and 10dB values of SNR, although after 15dB getting results bit closer to actual. We have also observed that end point detection method is more prone to noise but correlation methos has less impact of noise.

Conclusions

It can be inferred that the addition of white Gaussian noise has no effect on the calculation of distance and velocity when correlation processing is used, but it has a negative impact when end point detection is used. When we employ end point detection, a filter is very helpful as it allows us to maintain a lower threshold, which does not significantly affect relative distance results and makes the velocity profile fairly accurate. However, when we use a filter to suppress noise outside the bandwidth of the signal, it introduces delay and thus does more harm than good when we are using correlation processing.

References

1. https://in.mathworks.com/help/matlab/ref/corrcoef.html