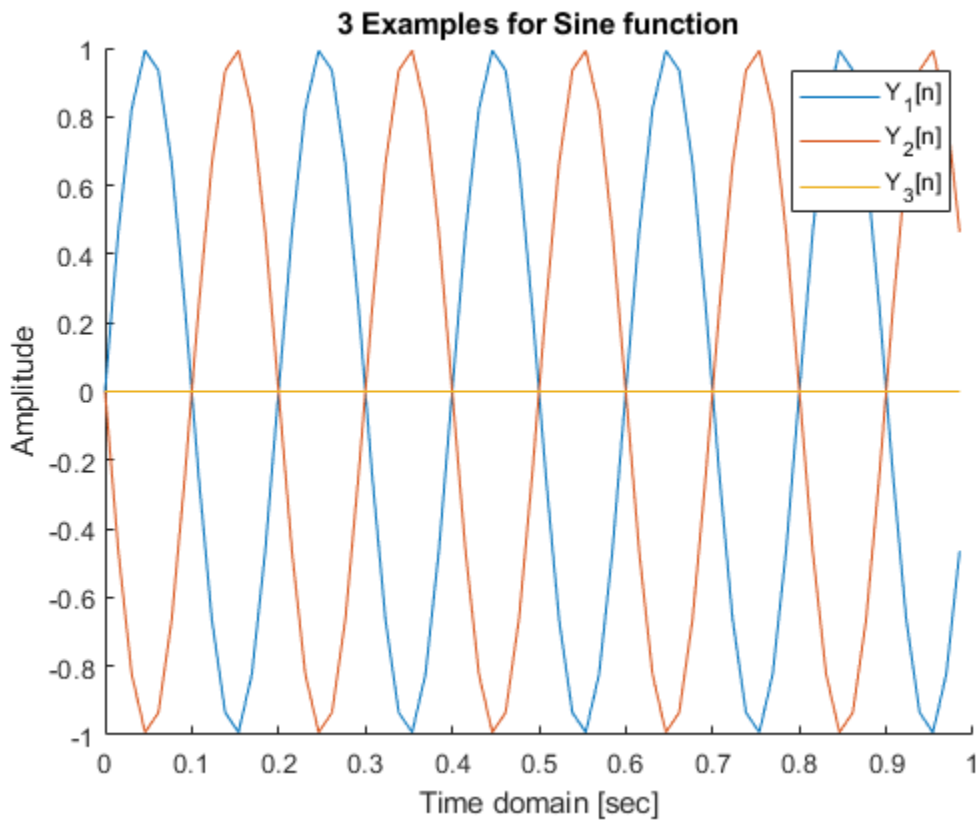
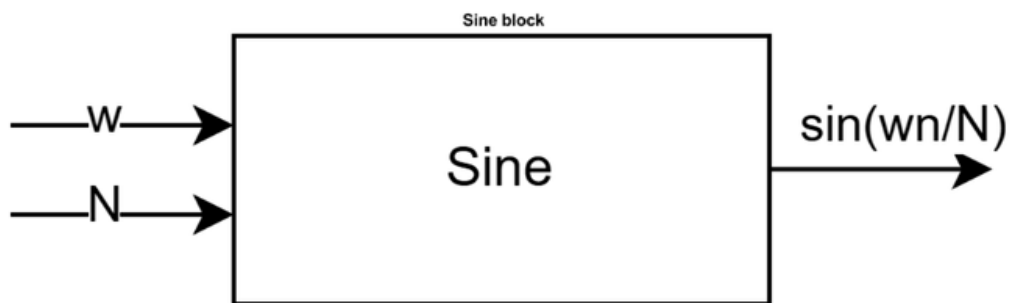

Sine examples

Lets show 3 basic examples using SINE function:

- $y_1[n] = \sin(2\pi 5t)$
- $y_2[n] = \sin(2\pi 5t + \pi)$
- $y_3[n] = y_1[n] + y_2[n]$

The second signal is delayed by π so we consider to get cosine instead. The third one, is the sum of sine and cosine with the same frequency, so we consider to get ZEROS:

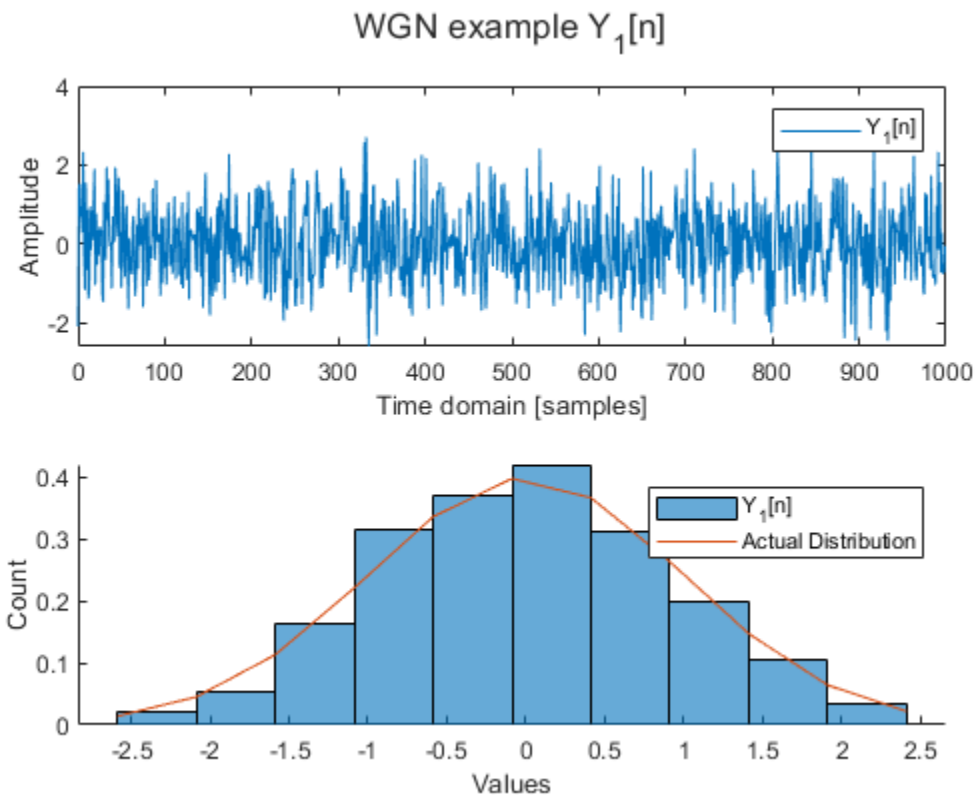
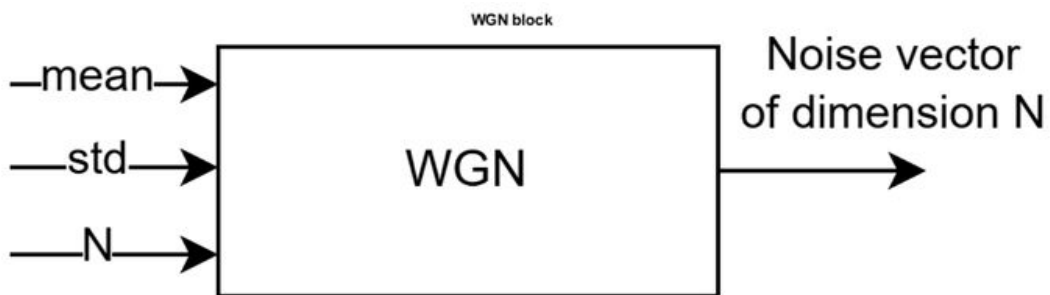


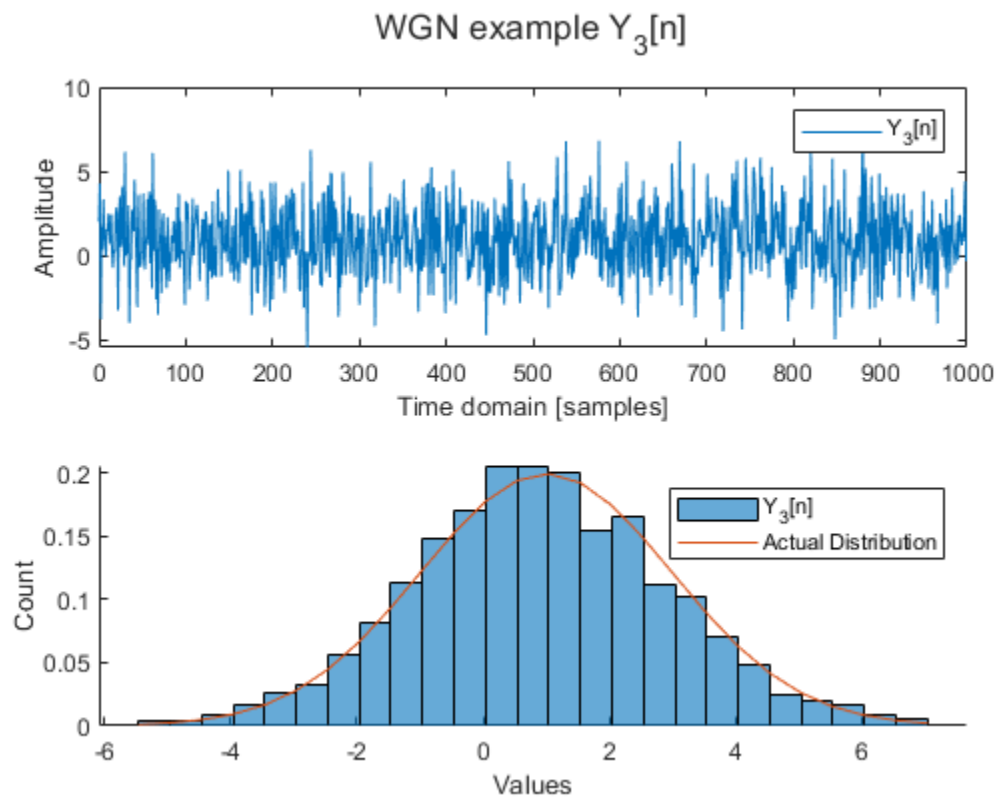
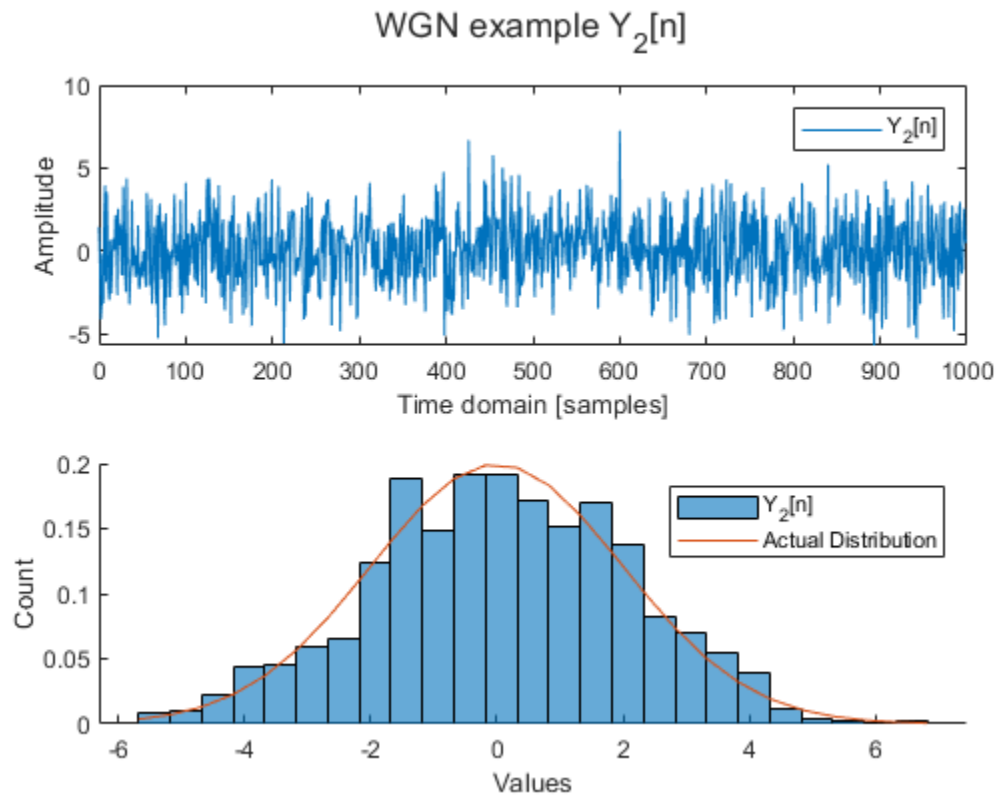
WGN examples

Let's generate 3 different levels of noise:

- $y_1[n] = WGN(N, 0, 1)$ - White gaussian noise
- $y_2[n] = WGN(N, 0, 2)$ - White gaussian noise with increased variance
- $y_3[n] = WGN(N, 1, 2)$ - White gaussian noise with increased variance and DC offset

The samples at different times are uncorrelated, so we expect to observe a random signal. Additionally, when examining the empirical probability density function (PDF), we expect to obtain a normal distribution with the parameters above:



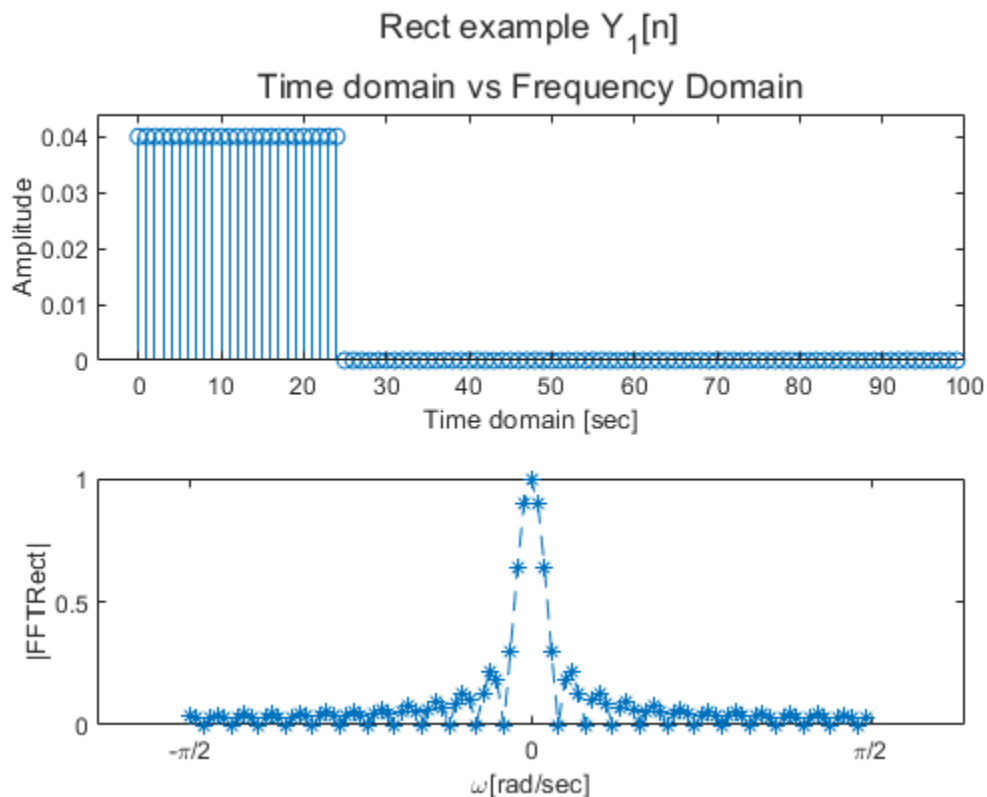
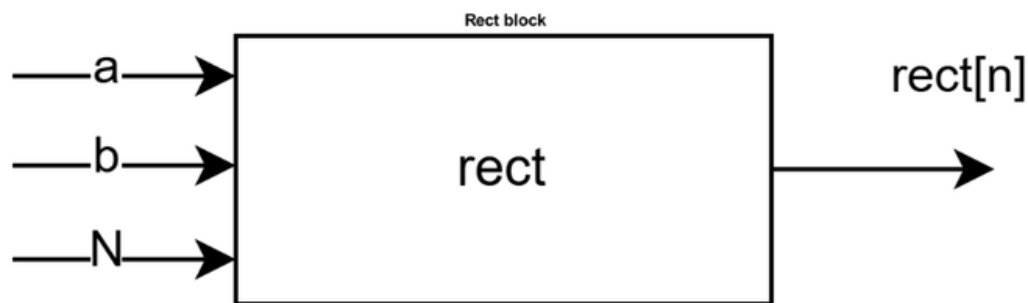


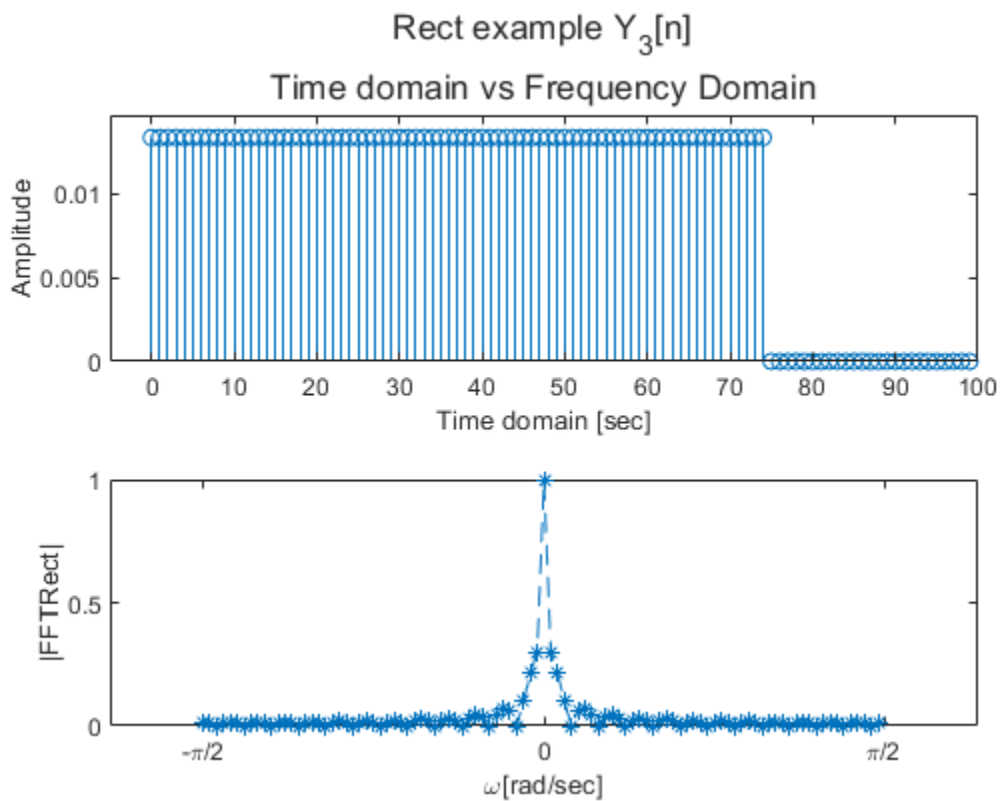
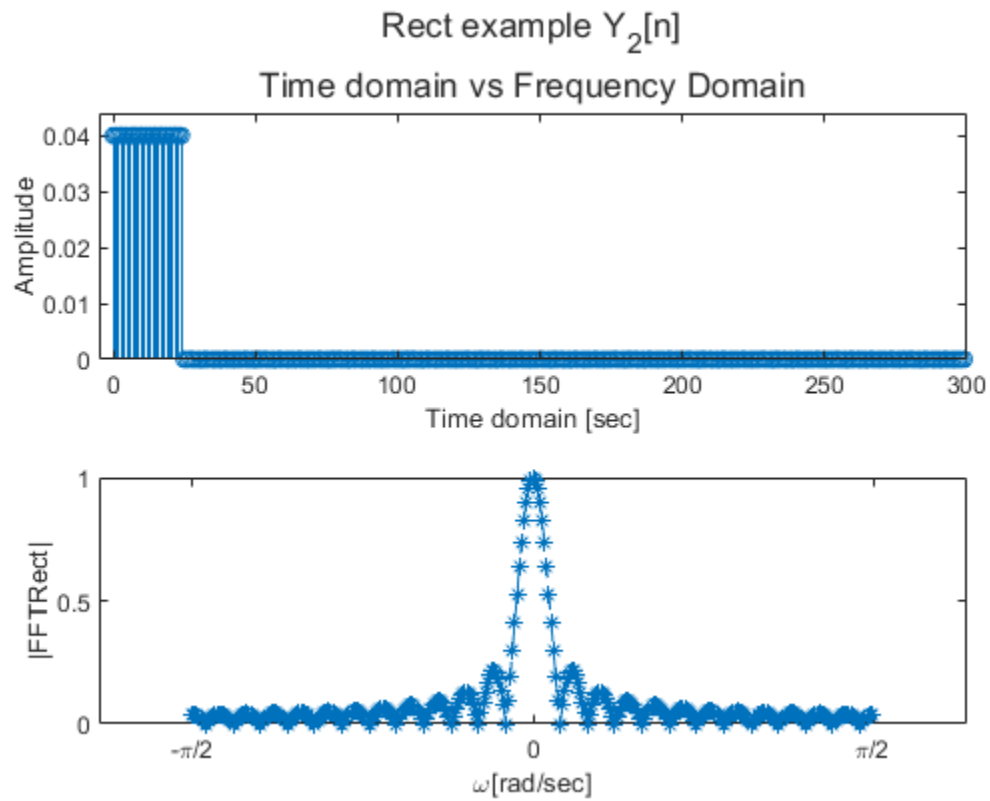
Rect examples

Let's consider 3 examples for Rect function: Let $N = 100$;

- $y_1[n] = \text{Rect}(0, 25, N)$ - window function between 0 and 25 with 100 samples
- $y_2[n] = \text{Rect}(0, 25, 3 * N)$ - same as $y_1[n]$ but also padded with additional 200 zeros at the end
- $y_3[n] = \text{Rect}(0, 75, N)$ - same as $y_1[n]$ but more time coverage - 0 to 75 with 100 samples

The DFT of $y_1[n]$ is SINC, when the signal is padded with zeros at the end the resolution in frequency domain improved ($y_2[n]$), so we get the same SINC as in case of $y_1[n]$ but with better resolution in frequency domain. And finally, when the window width increase the SINC width in frequency domain decrease approaching to $\delta(\omega)$. Lets show it:





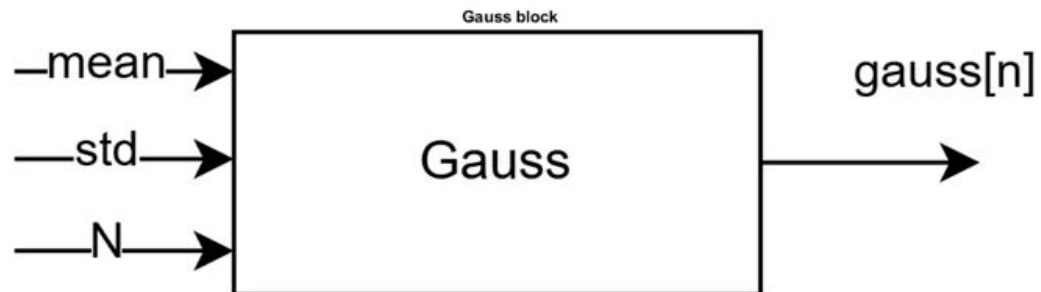
Gauss examples

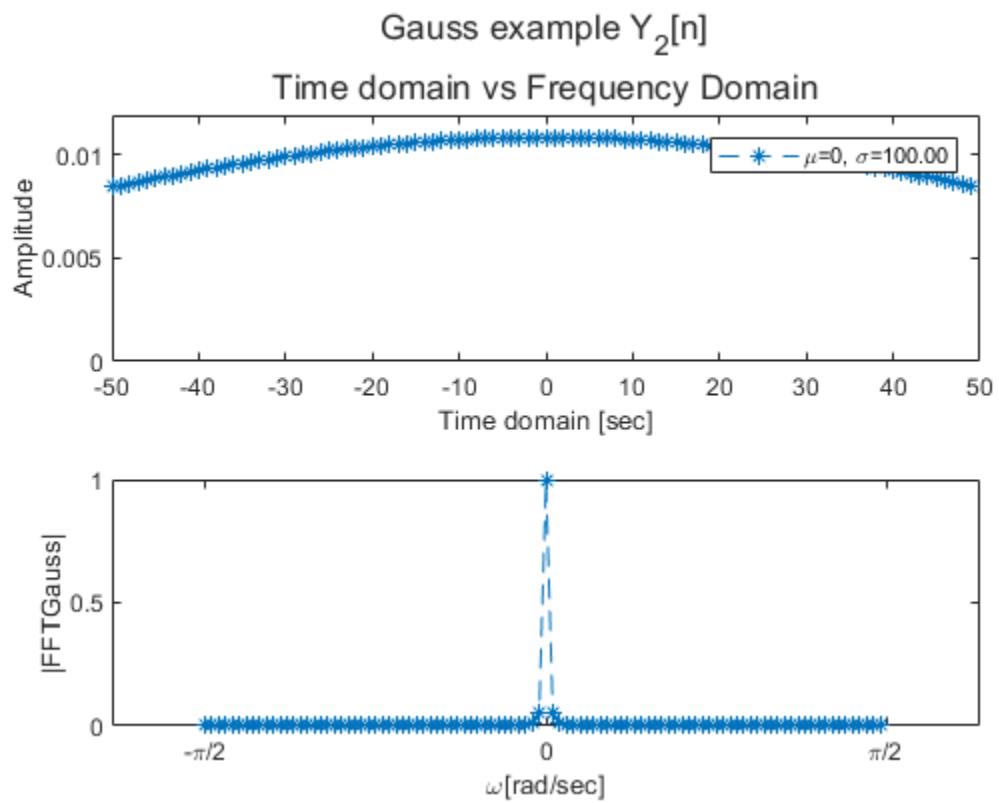
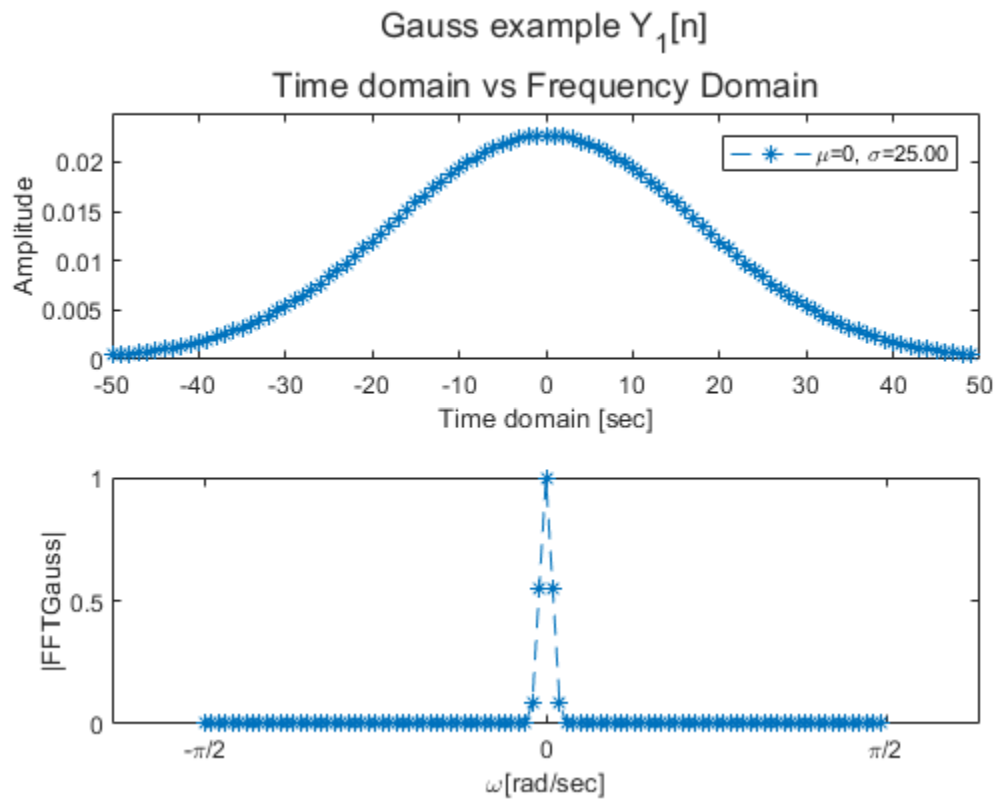
Let's consider 3 examples for Gauss function: Let $N = 100$;

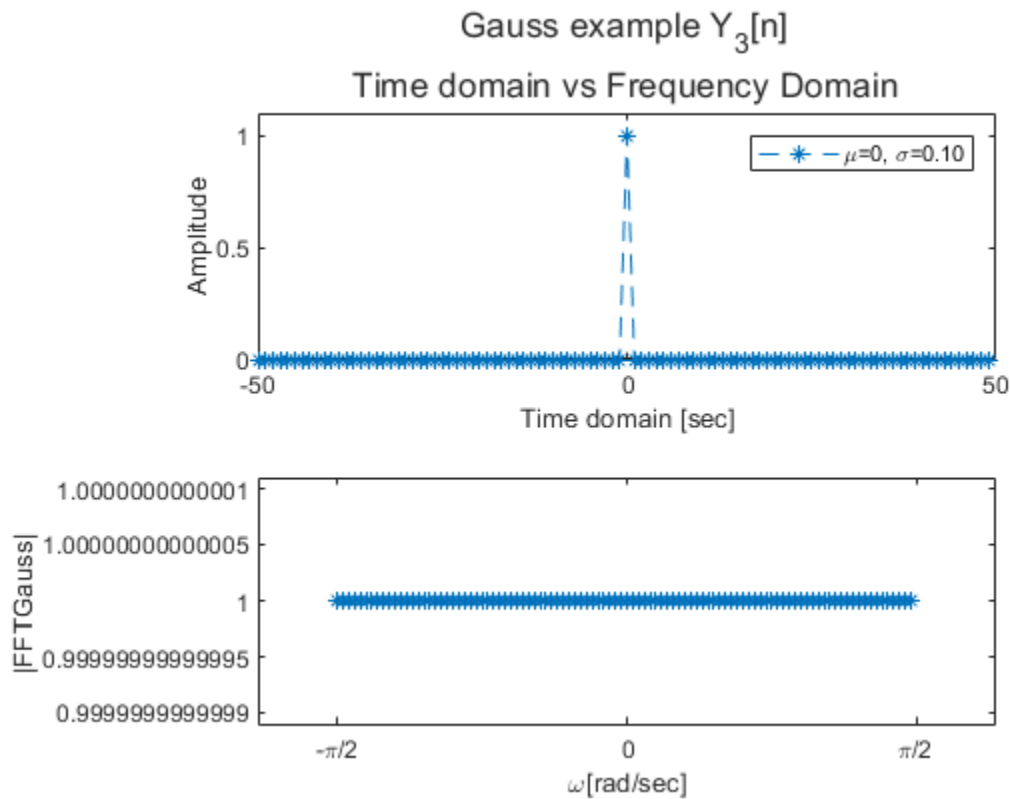
- $y_1[n] = \text{Gauss}(0, 25, N) \sim N(0, 25^2)$, 100 samples
- $y_2[n] = \text{Gauss}(0, 100, 2 * N) \sim N(0, 100^2)$, 100 samples
- $y_3[n] = \text{Gauss}(0, 0.1, N) \sim N(0, 0.1^2)$, 100 samples

The gaussian can be used as a window function. It's smoother than rect window. One can see, that when:

- $\sigma^2 \rightarrow \infty$ - it tends to be like infinite rect window\DC so the spectrum is $\delta(\omega)$
- $\sigma^2 \rightarrow 0$, it tends to be $\delta(t)$ so the spectrum is flat.
- $\sigma^2 < \infty$, it can be interpreted as smooth window with nice properties.







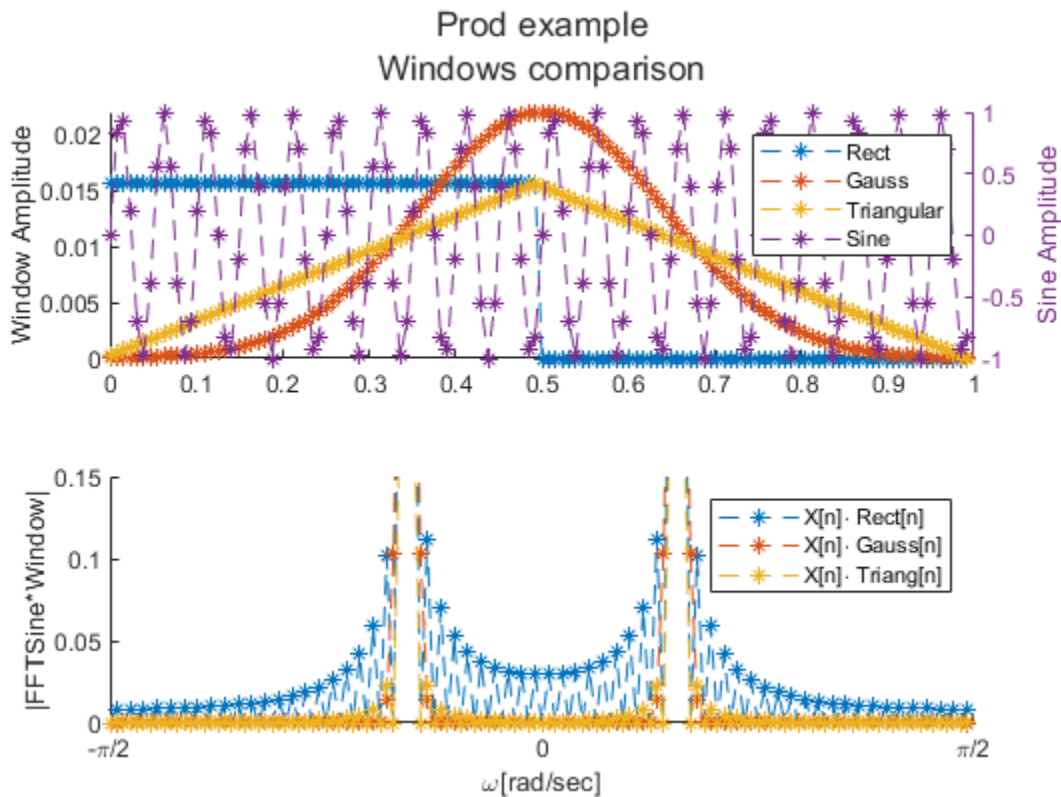
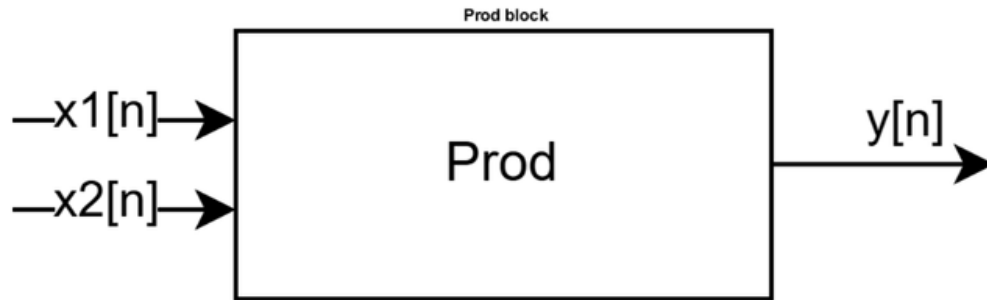
Prod examples

Let's consider 3 examples for Prod function: Let $N = 64$; $X[n] = \sin(2\pi \cdot 5n/N) - 1$ [sec] of the sine.

- $y_1[n] = X[n] * \text{Rect}(0, 0.5, N)$ - $X[n]$ multiplied by rect window (between 0 and 0.5[sec])
- $y_2[n] = X[n] * \text{Gauss}(0, 0.2, N)$ - $X[n]$ multiplied by Gauss window ($\mu = 0, \sigma = 0.2$)
- $y_3[n] = X[n] * \text{Triangle}$ - $X[n]$ multiplied by triangle window

Windows can be used to reduce artifacts that occurred due to the fact that the signal is finite. We will consider the 3 windows: Rect, Gauss and Triangle. As we have seen (044198):

- Rect response is Dirichlet func in frequency domain.
- Gauss is smoother than rect, so we expect to get lower sidelobes.
- Triangle is Dirichlet squared, so lobes should be lower comparing to rect.



Add examples

Let's consider 3 examples for Add function: Let $N = 64$; $X[n] = \sin(2\pi \cdot 5n/N) - 1$ [sec] of the sine. Noises we used few sections above:

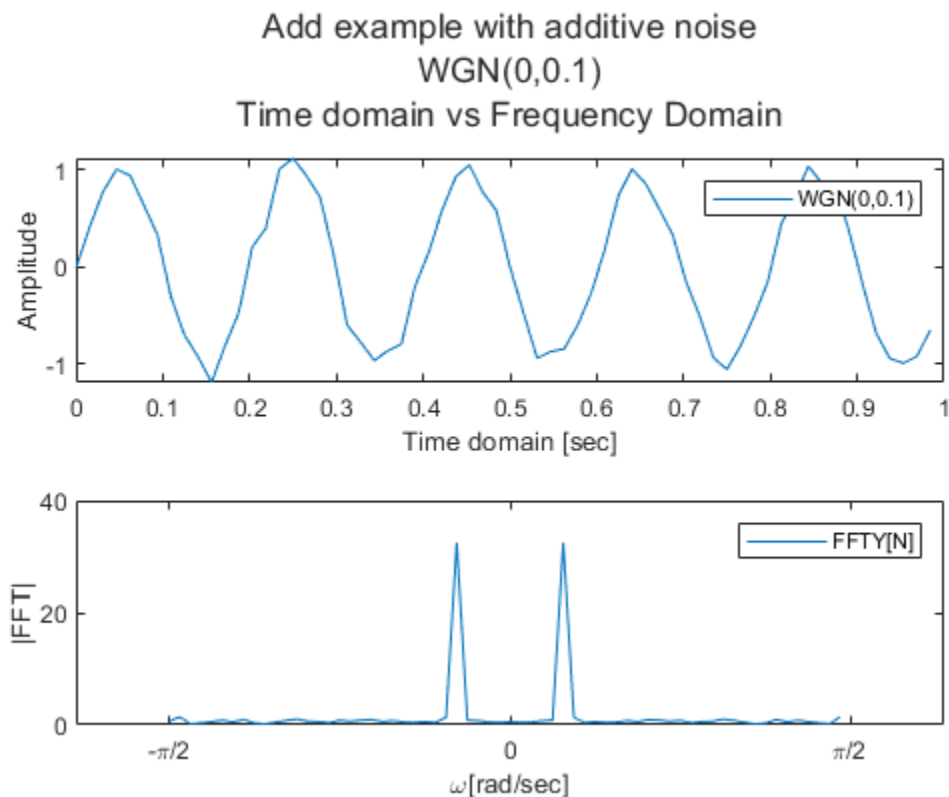
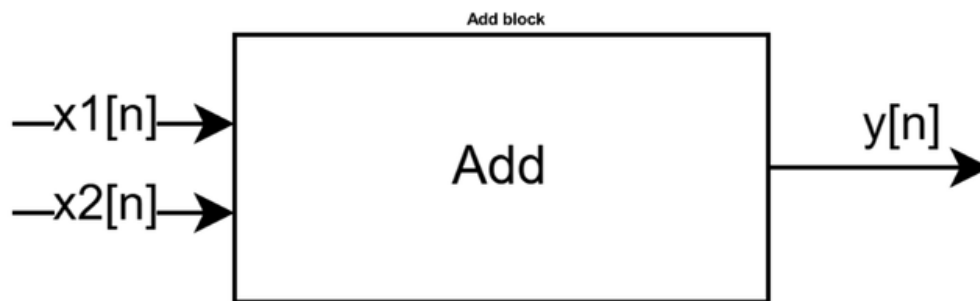
- $n_1 = WGN(N, 0, 0.1)$
- $n_2 = WGN(N, 1, 0.1)$
- $n_2 = WGN(N, 0, 1)$

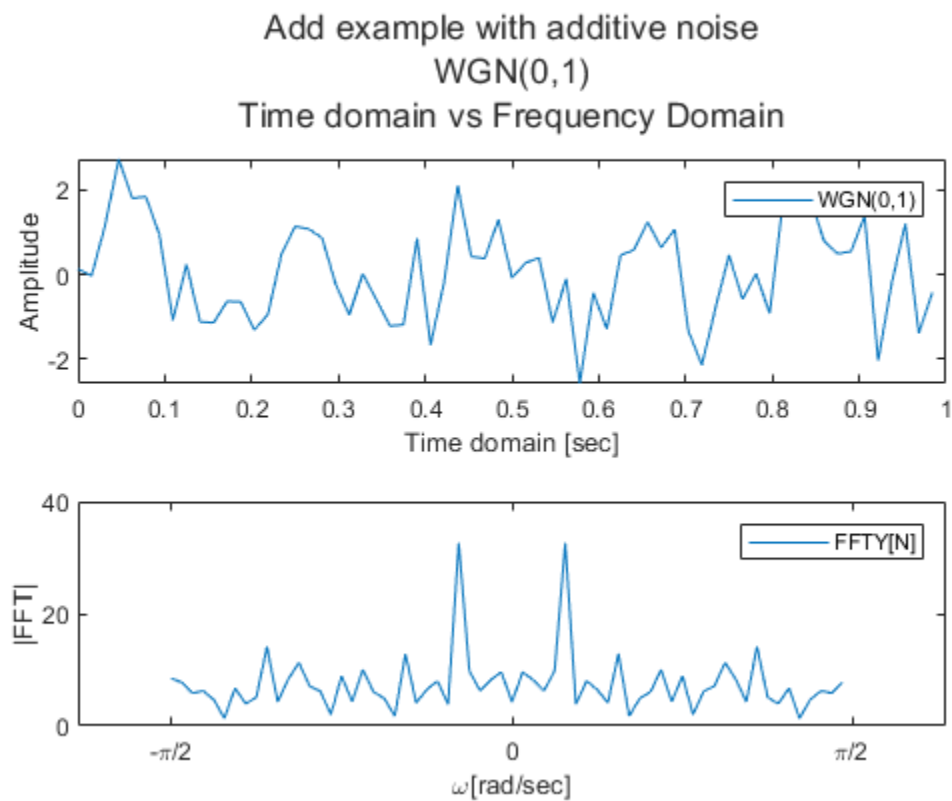
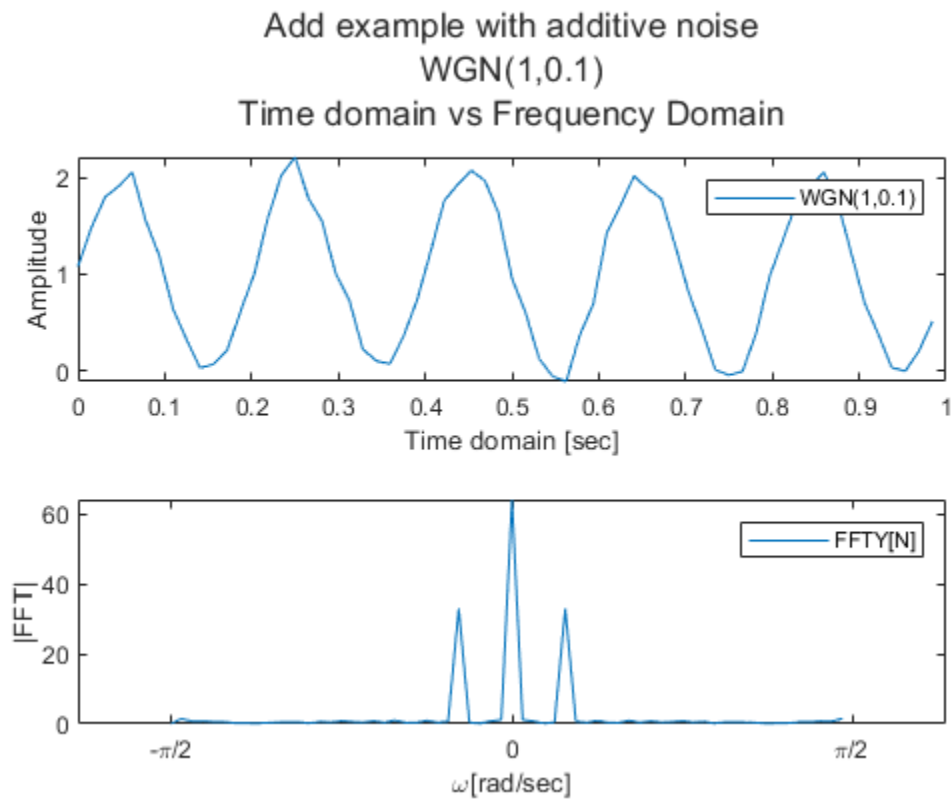
Let's consider:

- $y_1[n] = X[n] + n_1[n] - X[n]$ with low power noise
- $y_2[n] = X[n] + n_2[n] - X[n]$ with low power noise with "DC" ($\mu \neq 0$)
- $y_3[n] = X[n] + n_3[n] - X[n]$ with high power noise

We expect that:

- $y_1[n] \approx X[n]$ because the SNR is good enough
- $y_2[n] \approx y_1[n]$ but there will be DC frequency
- Finally, $y_3[n]$ will look differently than $X[n]$ because the SNR is bad, but in frequency domain we are able to see the deltas. Intuitively, that's because DFT does integration over time. Let's compute add operations:





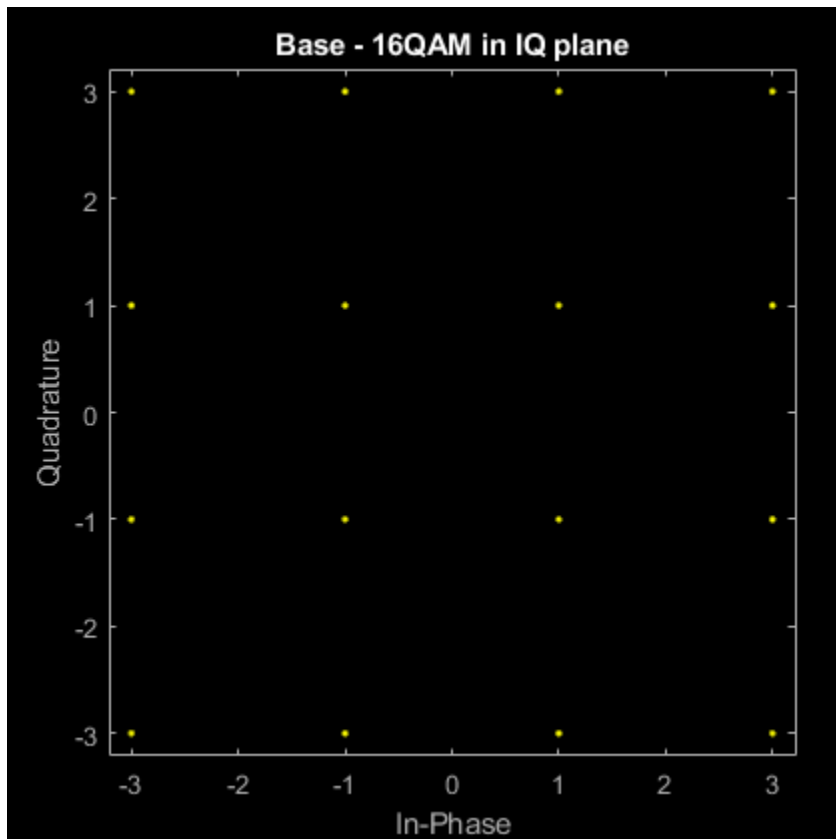
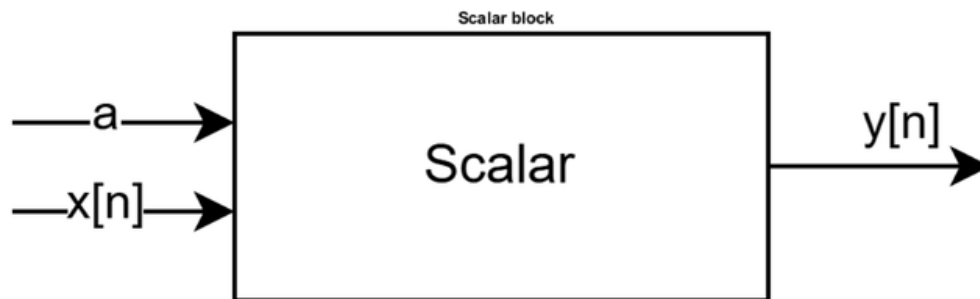
Scalar examples - Rotated 16QAM

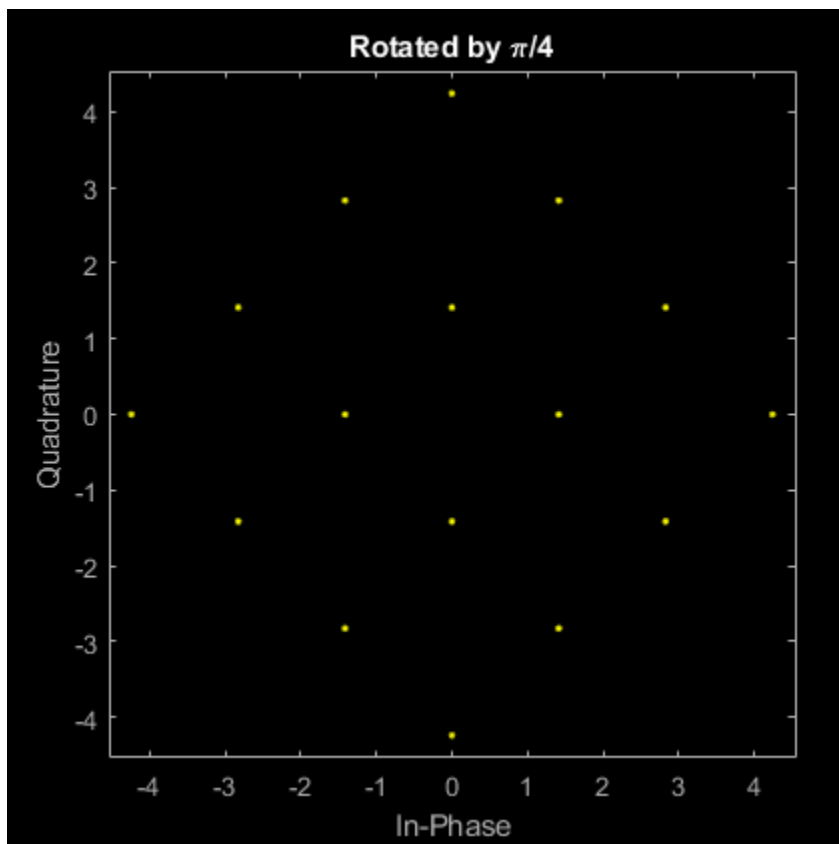
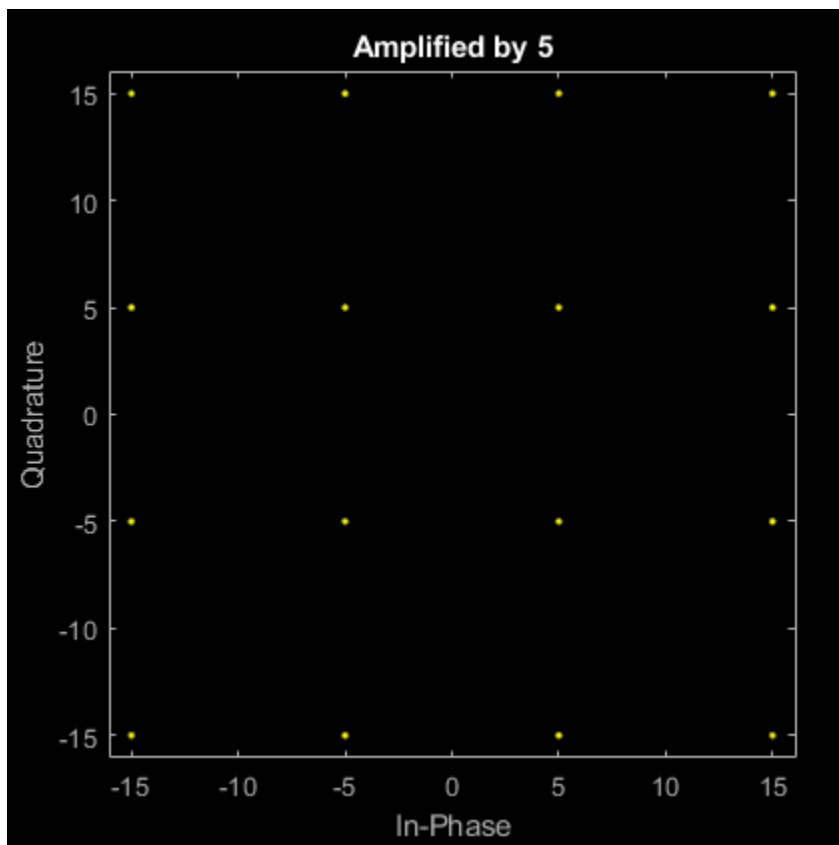
Let's consider 3 examples for Scalar function.

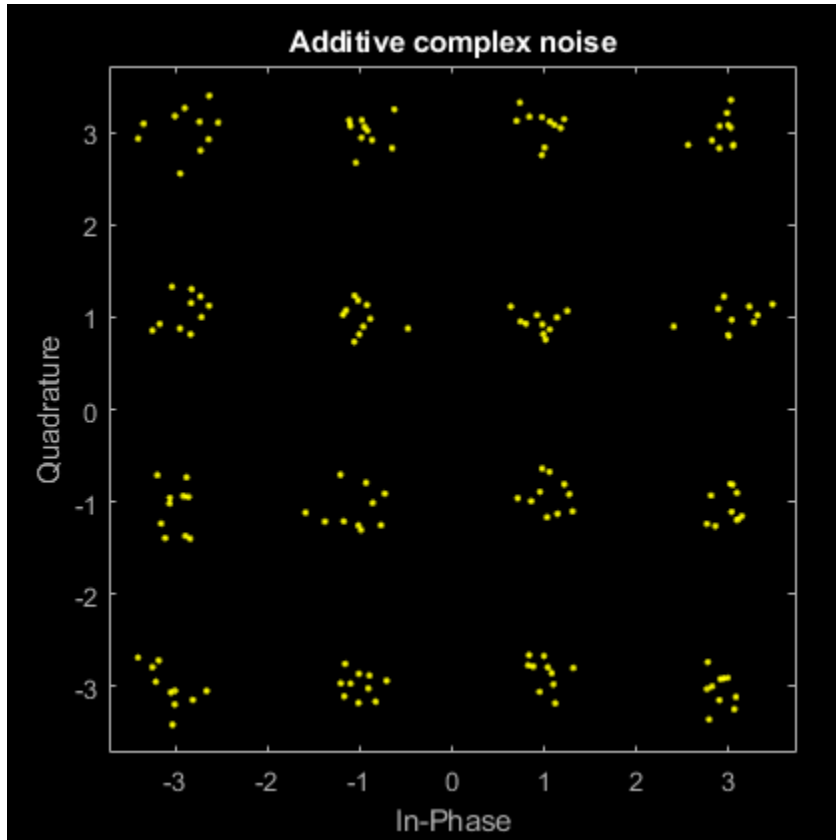
We will define set of complex numbers with 2 energy levels and phases $n\pi/4$ (16QAM symbols).

By multiplying these numbers by a scalar, we can observe interesting phenomenas. We will multiply by:

- a (Real scalar) - we expect that the energy of each symbol will increase by a .
 - $\exp(j\pi/4)$ - all of the symbols will be rotated by $\pi/4$
 - Add additive complex noise - the symbols will be normally distributed around the expected QAMs locations.
- Let's apply Scalar multiplications:







Filter examples

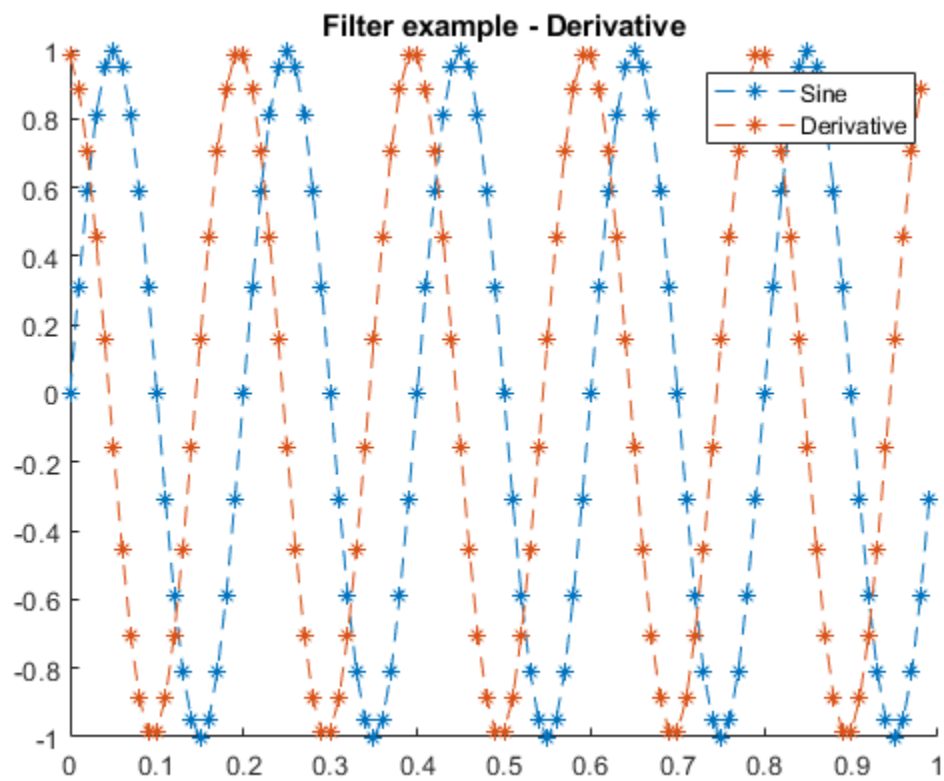
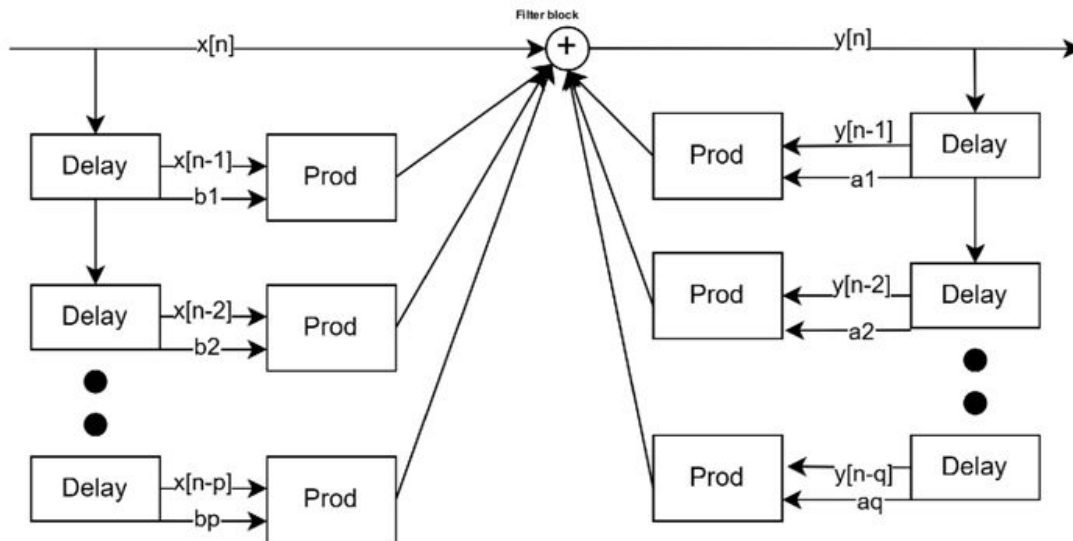
Let's consider 3 examples for Filter function:

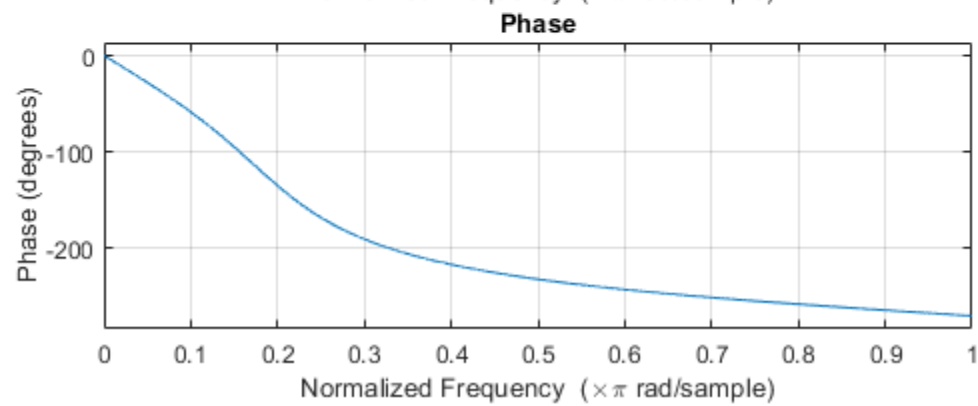
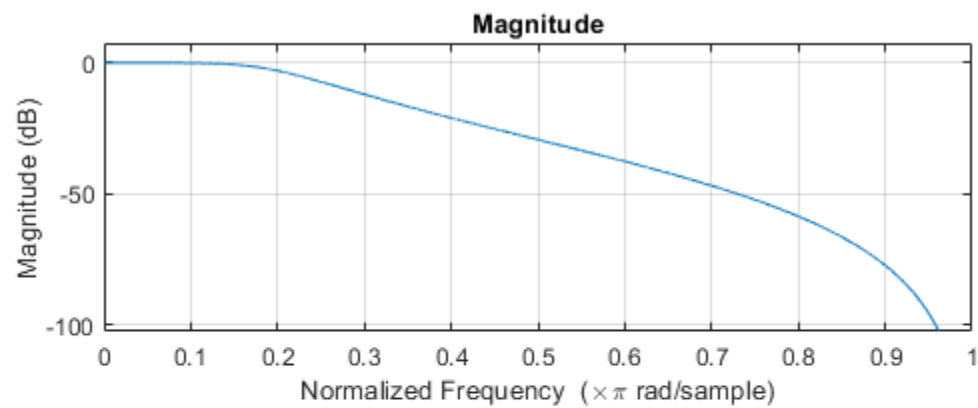
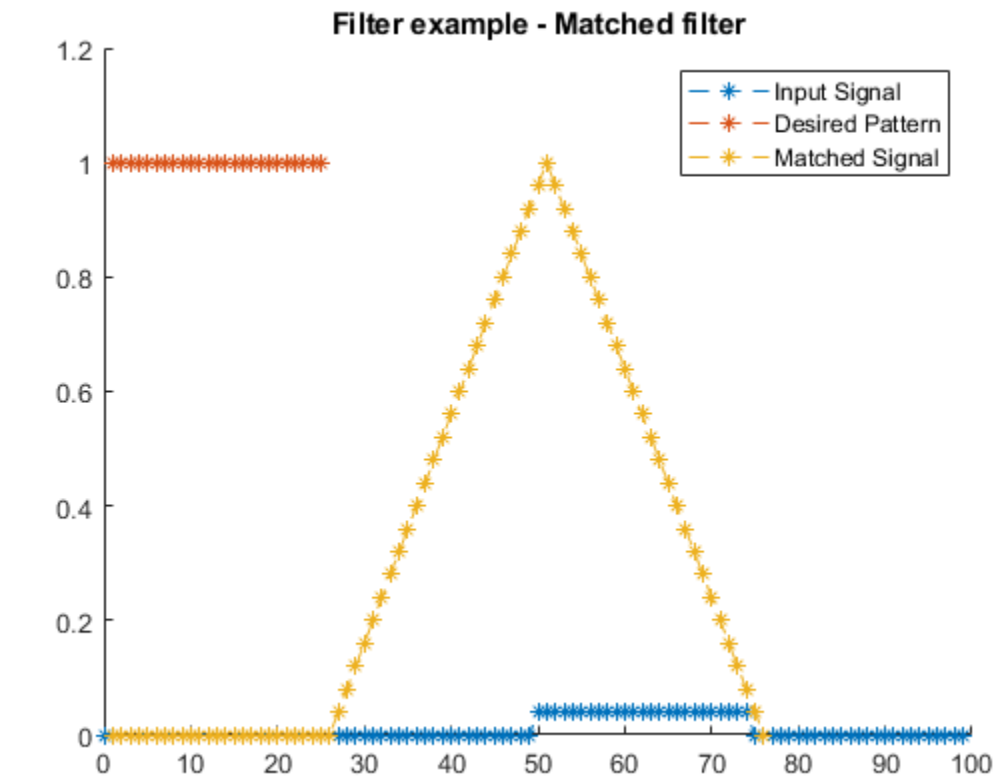
- $a_n = 1, b_n = [1, -1] * c$ - Derivative filter
- $a_n = 1, b_n = \text{ones}(1, M)$ - Matched filter
- $a_n = 1, b_n = \bar{\alpha}$ - Lowpass filter

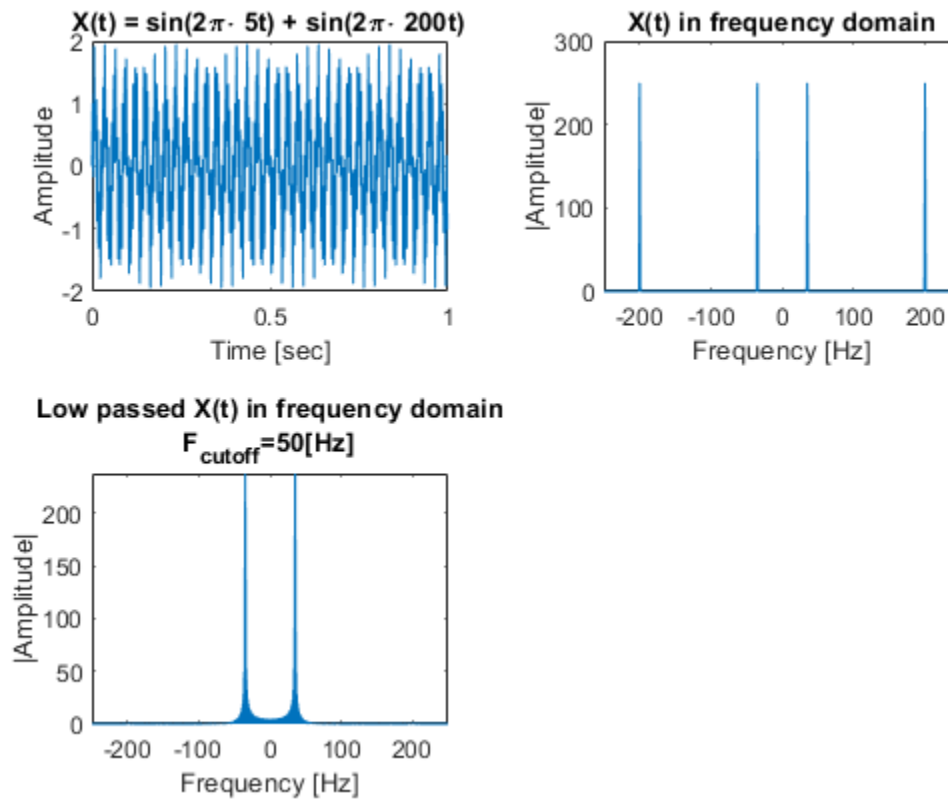
With derivative filter we will use $X(t) = \sin(2\pi \cdot 5t)$ as an input signal. We expect to get cosine.

With Matched filter we will use delayed Rect as an input signal and Rect as a pattern. We expect to get triangle as a matched signal results (convolution of rects), when the maximum will be placed at the beginning of the delayed rect on input signal.

With Lowpass filter we will use $X(t) = \sin(2\pi \cdot 35t) + \sin(2\pi \cdot 200t)$ as an input signal. We will design IIR lowpass filter, with $F_{cutoff} = 50[Hz]$, 3 order. We expect to get only the $\sin(2\pi \cdot 35t)$ as result. Let's apply filters:







Interpolate examples

Let's consider 3 examples for Interpolate function:

- $x_1[n] = \sin(2\pi \cdot 5n/64)$ - sine wave
- $x_2[n] = \text{Rect}(0, 0.5, 64)$ - rect window
- $x_3[n] = \text{Gauss}(0, 0.75, 64)$ - gauss window

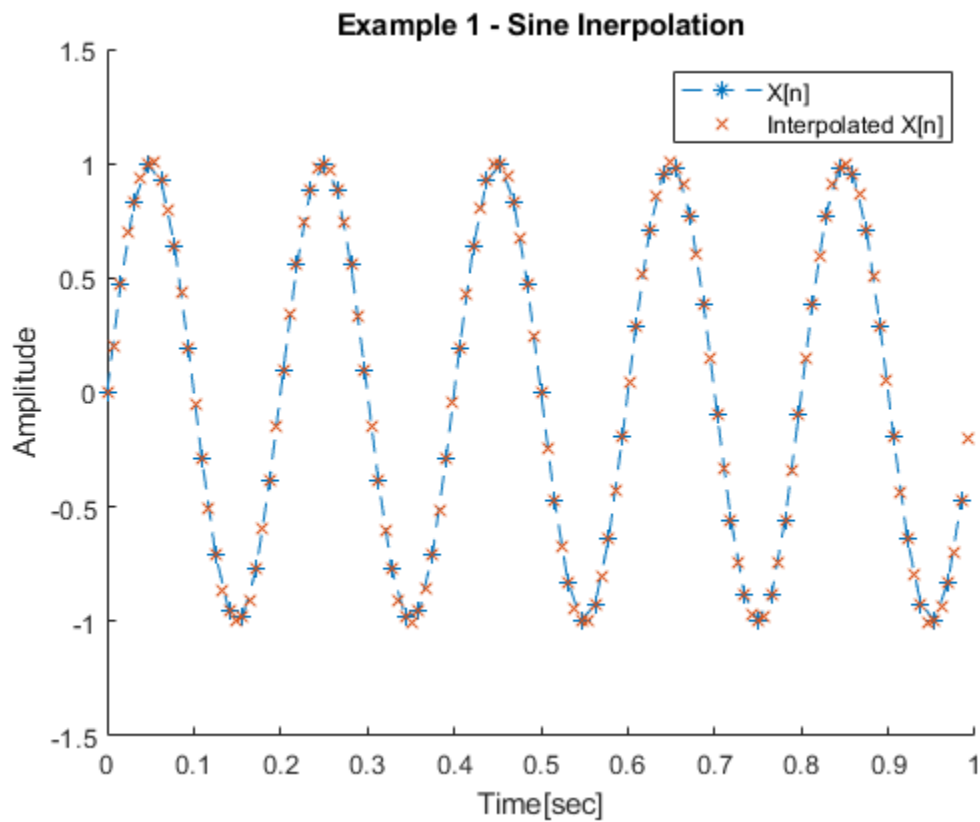
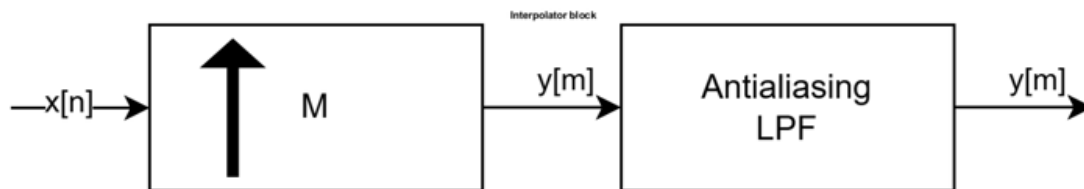
The signals have the following BW:

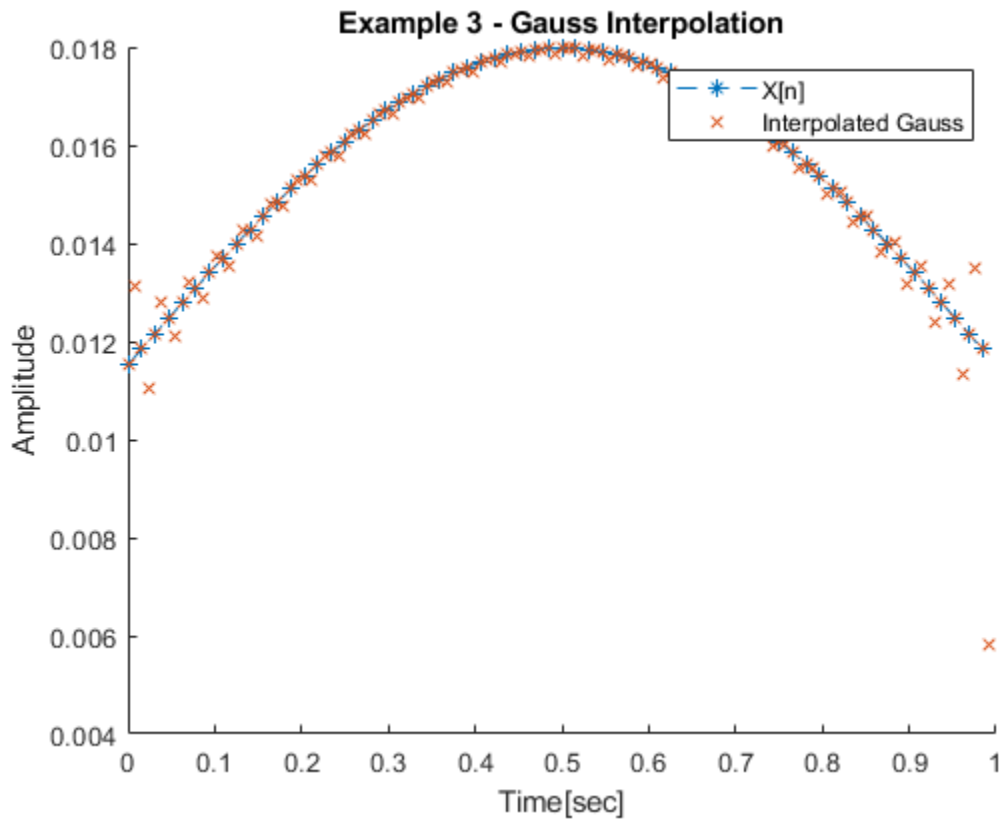
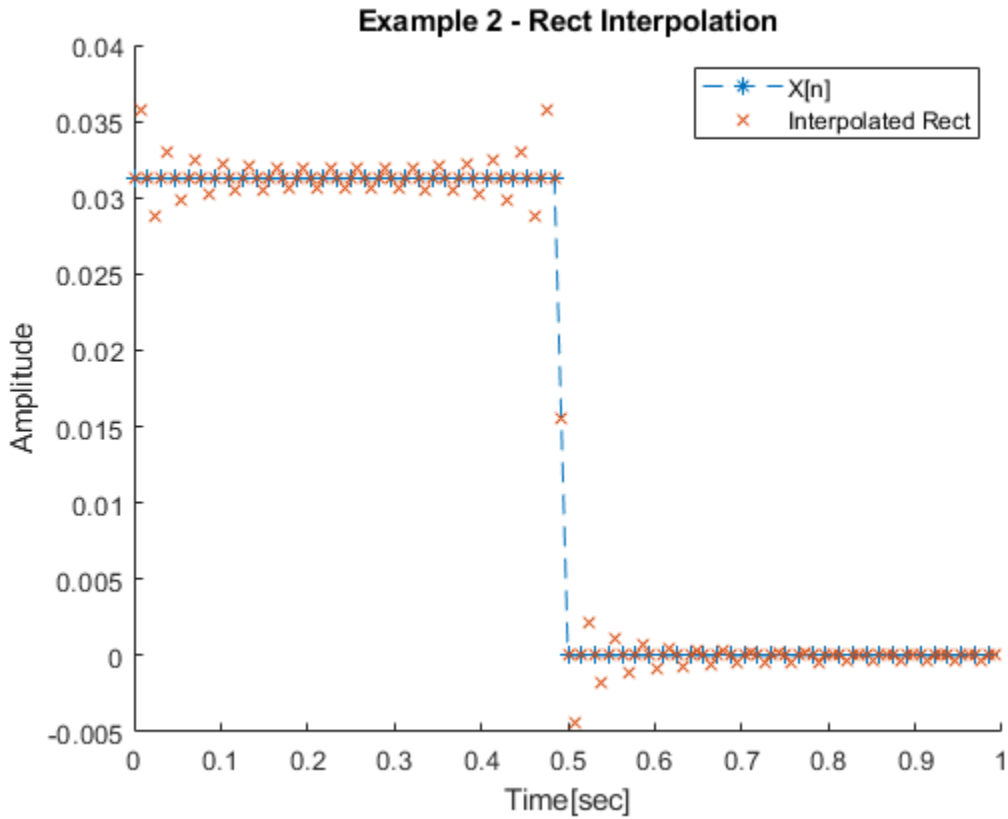
- $x_1[n]$ - $\delta(f + -5)$, so it's finite BW
- $x_2[n]$ - infinite sum of deltas in frequency domain, so it's infinite BW
- $x_3[n]$ - depending on σ^2 , it tends to include more\less high frequencies. if $\sigma^2 \rightarrow \infty$, the window has fast changes otherwise it changes "slowly", so we expect to get wide and narrow BW respectively

The fast changes implies kind of 'discontinuity' and we know (044198) that the reconstructed signal will converge to $(f(a^+) + f(a^-))/2$ when a represents a point of discontinuity. Furthermore, spectral artifacts such as the Gibbs phenomenon will be introduced into the signal.

So we expect that:

- $x_1[n]$ - no distortion at all because there is no discontinuity (if we take full period)
- $x_2[n]$ - Gibbs distortion will occur because the signal has discontinuity
- $x_3[n]$ - will be slightly distorted because there is 'smaller' discontinuity (only at the edges)





Decimate examples

Let's consider 3 examples for Decimate function: (Same as for interpolation)

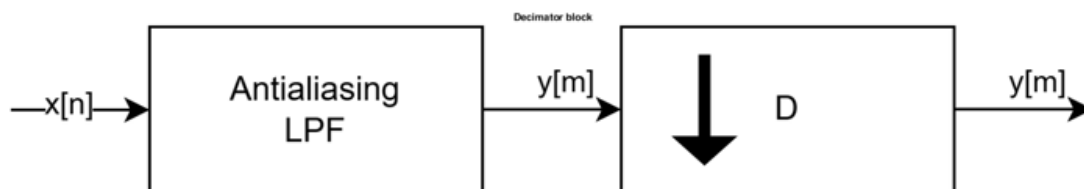
- $x_1[n] = \sin(2\pi \cdot 5n/64)$ - sine wave
- $x_2[n] = \text{Rect}(0, 0.5, 64)$ - rect window
- $x_3[n] = \text{Gauss}(0, 0.75, 64)$ - gauss window

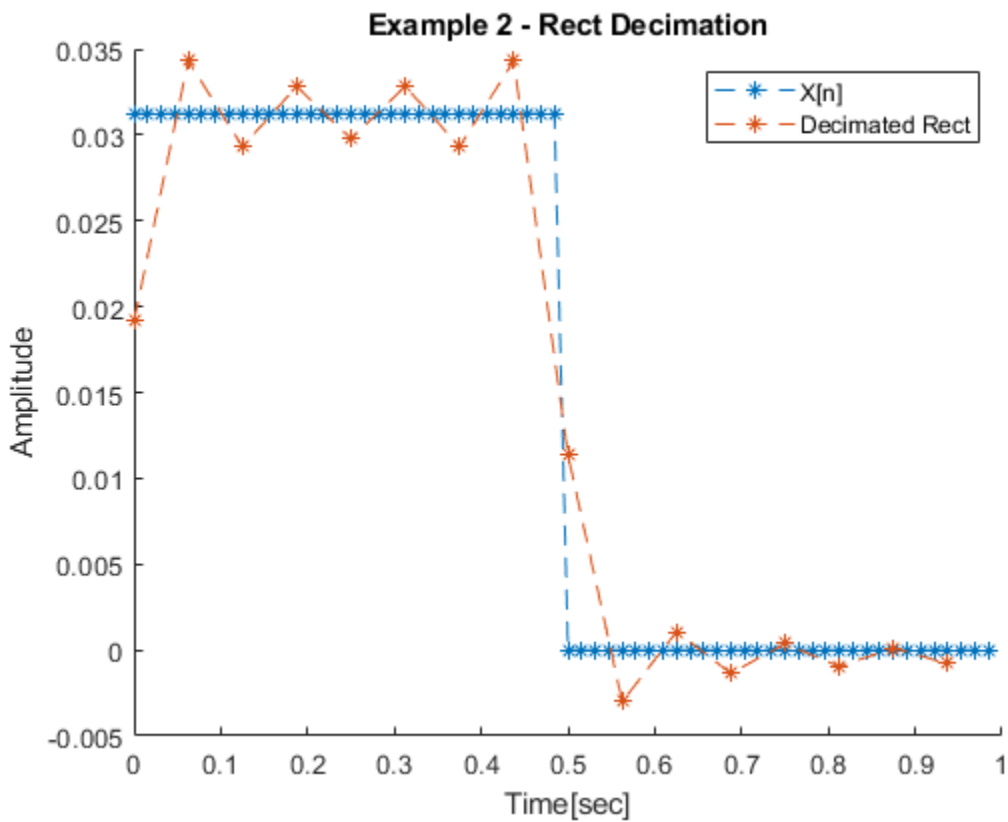
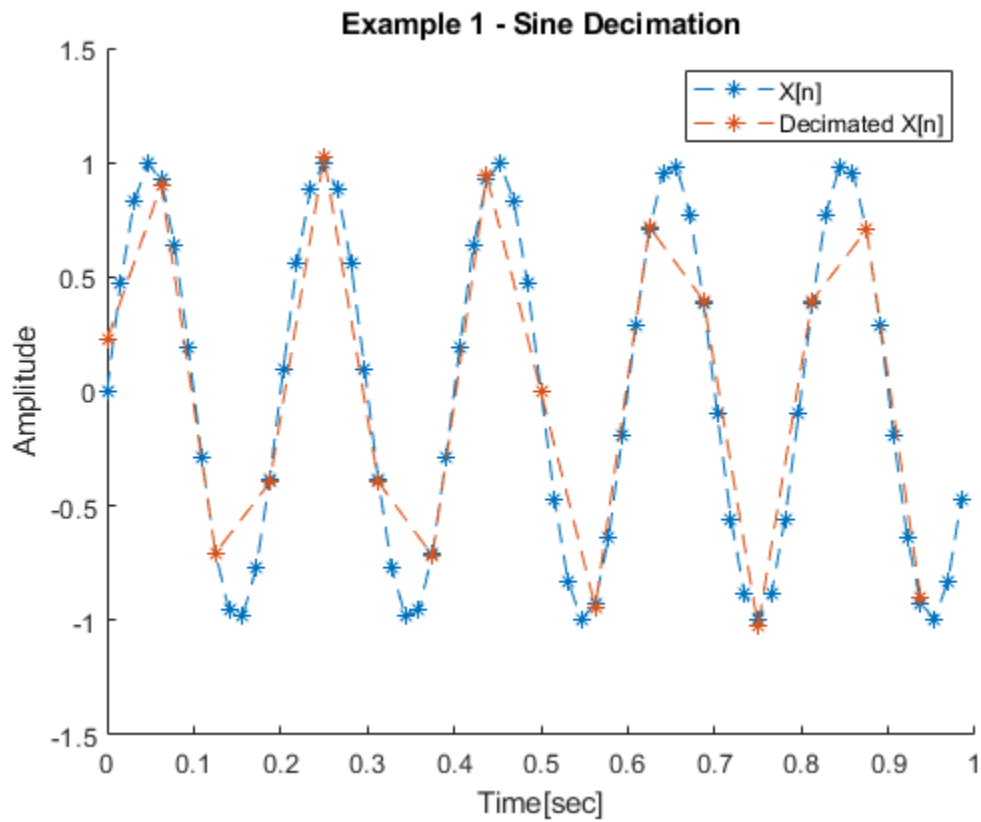
Each of the signals above has different BW:

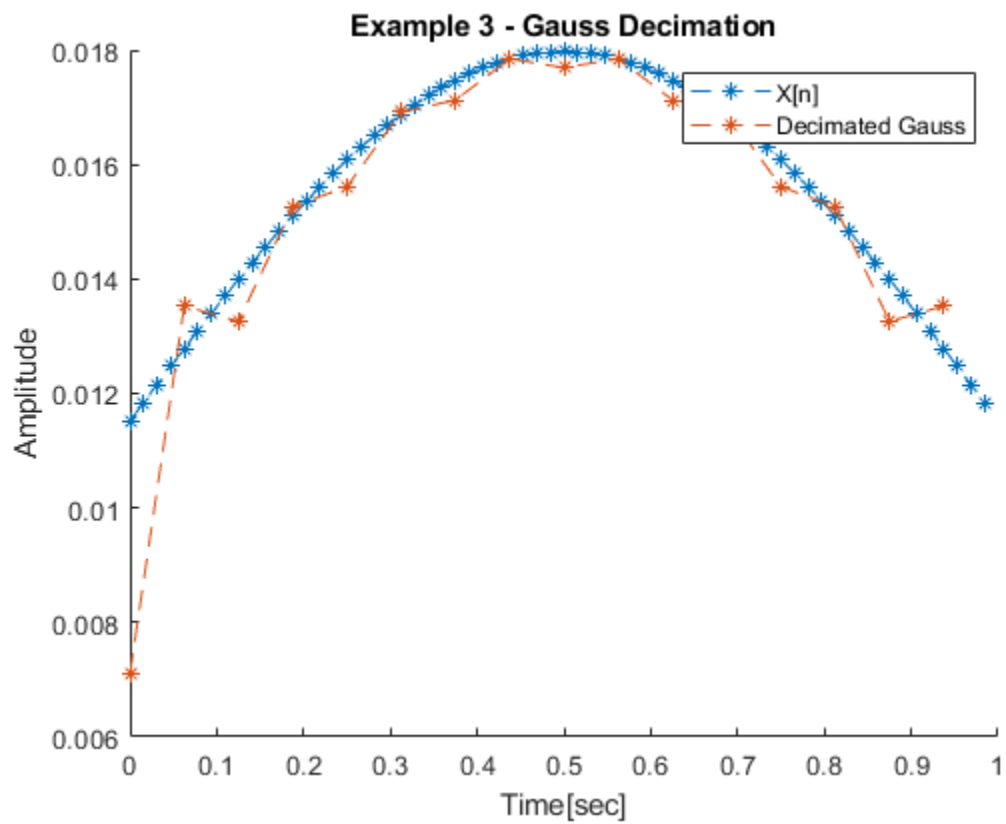
- $x_1[n]$ - $\delta(f + 5)$, so it's finite BW
- $x_2[n]$ - infinite sum of deltas in frequency domain, so it's infinite BW
- $x_3[n]$ - depending on σ^2 , it tends to include more/less high frequencies. if $\sigma^2 \rightarrow \infty$, the window has fast changes otherwise it changes "slowly", so we expect to get wide and narrow BW respectively.

As a part of decimation, we filter out some of the high frequencies in order to avoid aliasing, so the reconstructed signal is composed of smaller BW. So we expect that decimated signals:

- $x_1[n]$ - still can be seen as periodic wave (if the F_{cutoff} high enough), otherwise will be filtered out.
- $x_2[n]$ - the reconstructed signal will be composed with less amount of deltas, so we will get more distortion/Gibbs phenomenon.
- $x_3[n]$ - similarly to $x_2[n]$ but $x_3[n]$ is smoother, so we expect get less distortion than in $x_2[n]$ case (because it contains less high frequencies).







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