BERZIET UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ENEE 4113

communication Laboratory.

Experiment 6

Pulse Amplitude Modulation – Part2

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Section # : 3

Date: 4.2.2021

1. Abstract:

In this experiment, the student will be introduced to how they can deal with Pulse Amplitude modulation using written python code in GitHub simulator, they will emphasize the sampling theorem and talks about the relation between signal frequency and sampling frequency. After that we will talk about time division multiplexing and its power in communication.

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2.1 The Sampling Theorem:

In this section we will sample three cosine signals with different bandwidths (fm) to see the relation between the signal frequency fm and the sampling frequency fs. We will start with fs>2W, then fs=2W, and finally fs<2W.

2.1.1 Case 1: fs > 2W:

We will plot the message signal $m(t)=1*\cos(2\pi(10)t)$.
fm = 10 while fs=100 which means that $fs>2fm$, the plots shown below.

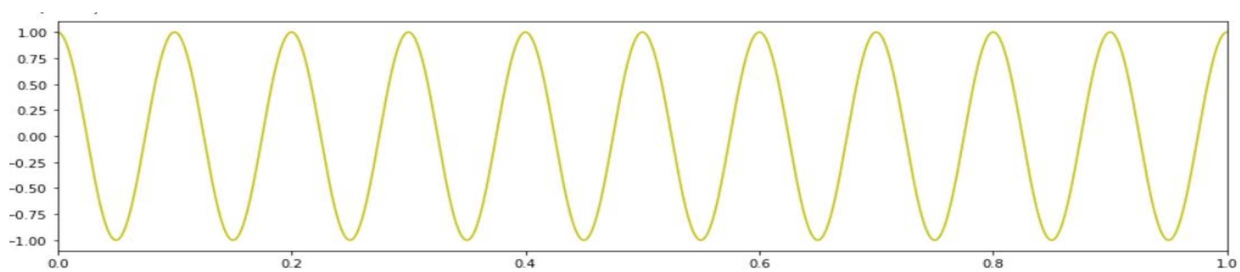


Figure 1:message signal with Fm=10

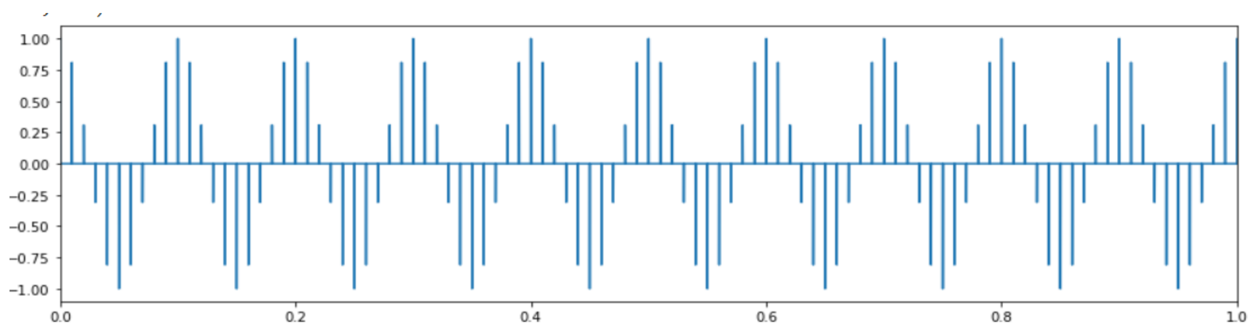


Figure 2:sampled signal with Fs=100

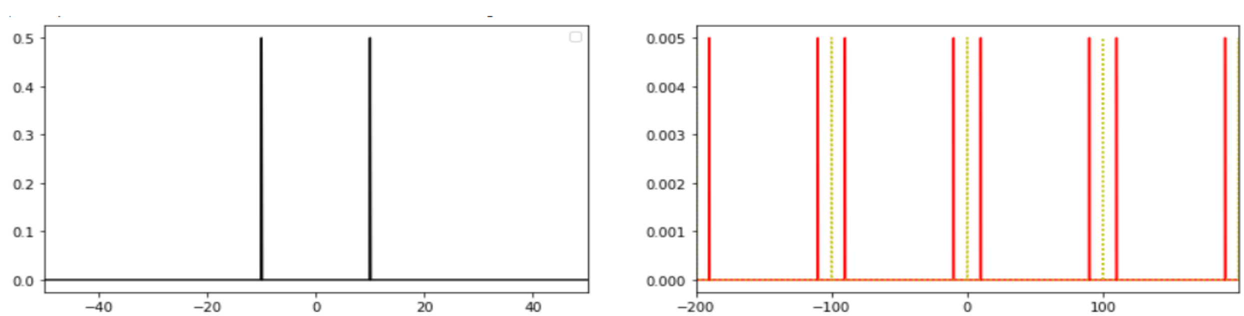


Figure 3: massage signal and convolution signal in frequency domain

- **Note**: In fiigure1 shows the message signal, figure2 shows the train of impulses signal, figure3 in left part show the massage signal in frequency domain but in right part show the sampled signal in red and the train of impulses that sampled on it in yellow color.

Now let’s try to reconstruct the signal using LPF with cut-off frequency = fs/2, the results in the following:

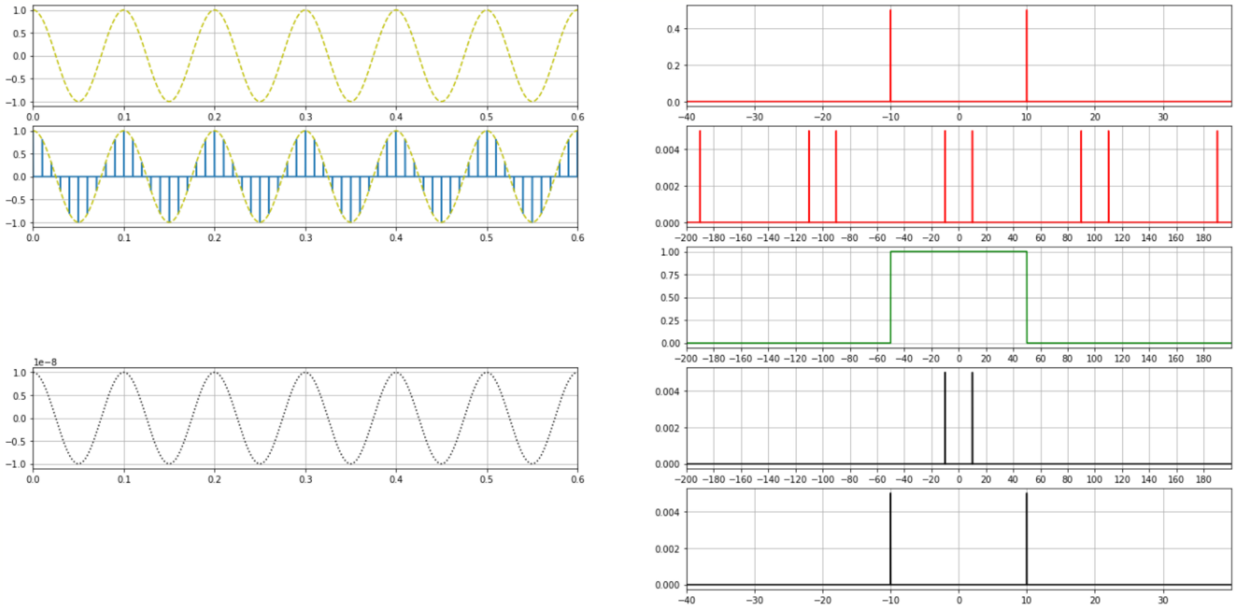


Figure 4:massage, sampling and recovered massage signal

- **<u>Note</u>:** from above figure we show two part, left part shows all the signals in time domain, the 1st plot from the top shows the message signal, then the sampled signal, then the reconstructed signal. And in the right part we show all the signal in frequency domain, the 1st plot from the top shows the message signal, then the sampled signal, then the LPF with cut-off frequency used for reconstruct the signal, then the reconstructed signal so in this case we can recovered the massage signal, the last plot shows the reconstructed signal zoomed-in.

Exercise:

1- **let change fm=30:**

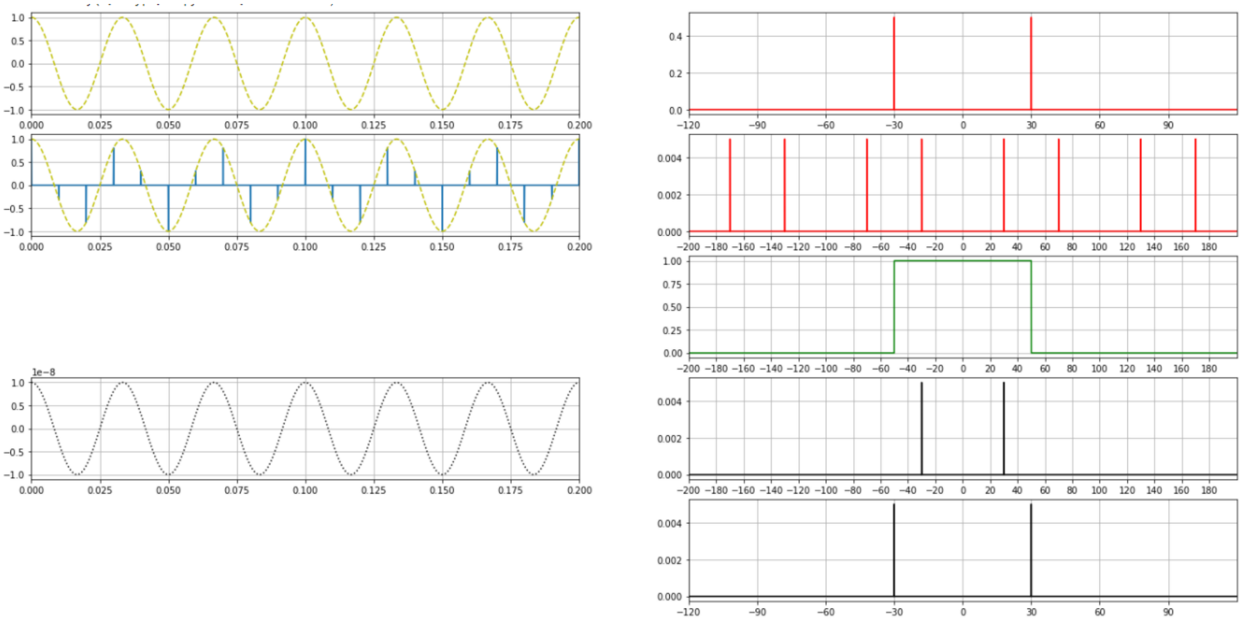


Figure 5:massage, sampling and recovered massage signal when fm=30

- **Note**: in this case when change fm=30 (fm increased) we notice:
  1- The frequency of massage signal change and moved away from each other and the BW change because the frequency change.
  2- The frequency for sampled signal change by (fs-nfm , fs+nfm), n: integer number, also we notice when increase the value of fm the upper side band for the left signal(fs small) getting close to lower side band for the right signal (fs large). For example: the upper side band for fs=0 [0+1*30=30] is getting close to lower side band for fs=100[100-1*50=50]. And this idea will be cleared when changed fm=45 in next part of exercise.
  3- When the fm value is changed, this does not effect on cut-off value for LPF and the filter is still able to pass the Signal because fm < cut-off.
  4- Finally, we notice when the signal pass from LPF we still can recovered the massage signal.

2- let change fm=45:

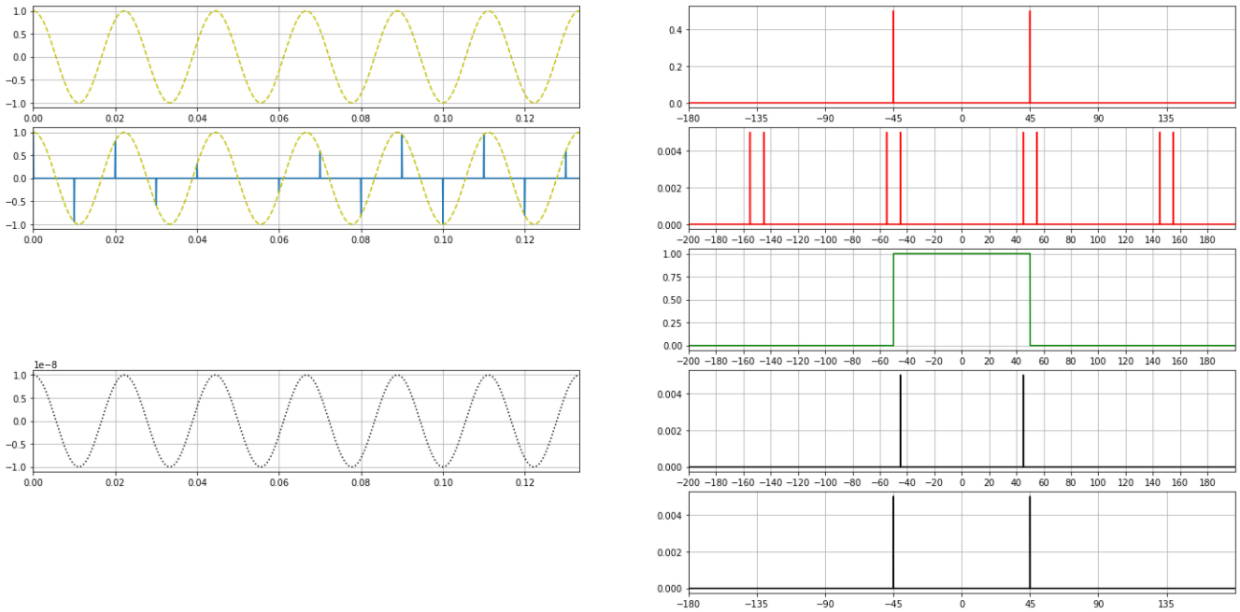


Figure 6:massage, sampling and recovered massage signal when fm=45

- **Note**: in this case when change fm=45 (fm increased) we notice:
  1. The frequency of massage signal change and moved away from each other and the BW change because the frequency change.
  2. The frequency for sampled signal change by (fs-nfm , fs+nfm), n: integer number, also we notice when increase the value of fm the upper side band for the left signal (fs small) getting close to lower side band for right signal (fs large). For example: the upper side band for fs=0[0+0*45=45] is getting close to lower side band for fs=100 [100-45=55].
  3. When the fm value is changed, this does not effect on cut-off value for LPF and the filter is still able to pass the Signal because fm < cut-off.
  4. Finally, we notice when the signal pass from LPF we still can recovered the massage signal.

3- let change Am=3:

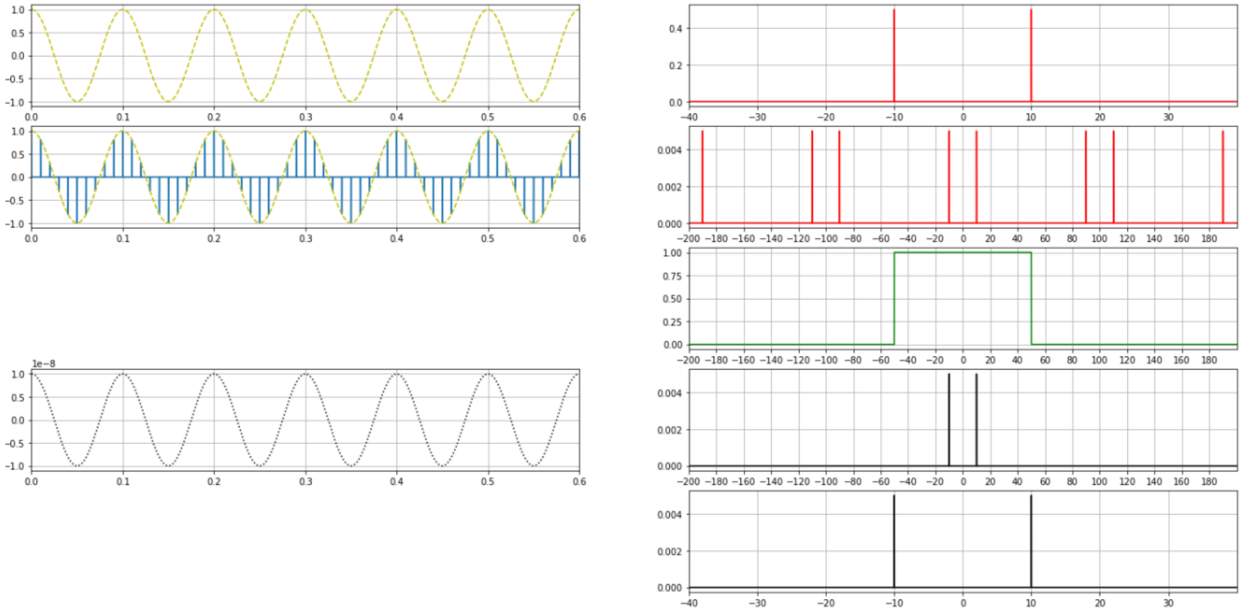
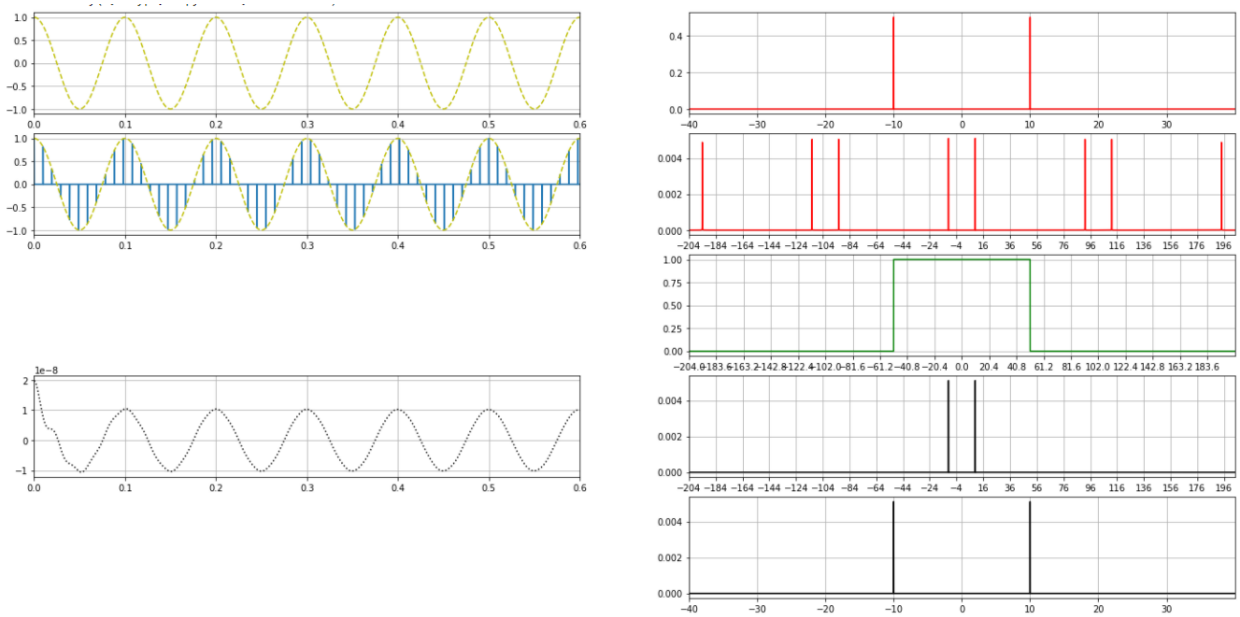


Figure 7:massage, sampling and recovered massage signal when Am=3

- **Note**: in this case when change Am=3 (Am increased) we notice:
  1- The amplitude for massage frequency changed by Am/2 but the BW doesn't change because the frequency has not change.
  2- The amplitude for sampled frequency change because it is due to the product of the massage signal by train of impulses so when the amplitude for massage frequency change the amplitude for the sampled signal will be change.
  3- When the Am value is changed, this does not effect on cut-off value for LPF and the filter is still able to pass the Signal because fm < cut-off.
  4- Finally, we notice when the signal pass from LPF we still can recovered the massage signal but the amplitude for this massage is different from original massage but we can use amplifier to get the same amplitude as the amplitude of the original massage.

4- <u>let change fs=102:</u>



- **<u>Note</u>**: in this case when change fs=102 (still fs<2fm) we notice:
  1- The frequency of massage signal doesn't change and the BW doesn't change because the frequency doesn't change.
  2- The frequency for sampled signal change by (fs-nfm , fs+nfm), n: integer number.
  3- When the fs value is changed, this effect on cut-off value for LPF by fs/2 and the filter is still able to pass the Signal because fm < cut-off.
  4- Finally, we notice when the signal pass from LPF we still can recovered the massage signal, but we notice we have some of distortion but this does not affect that much.

2.1.2 <u>**Case 2: fc = 2W(Nyquist rate):**</u>

We will plot the message signal $m(t)=1*\cos(2\pi(50)t)$.
fm = 50 while fs=100 which means that $fs=2fm$, the plots shown below.

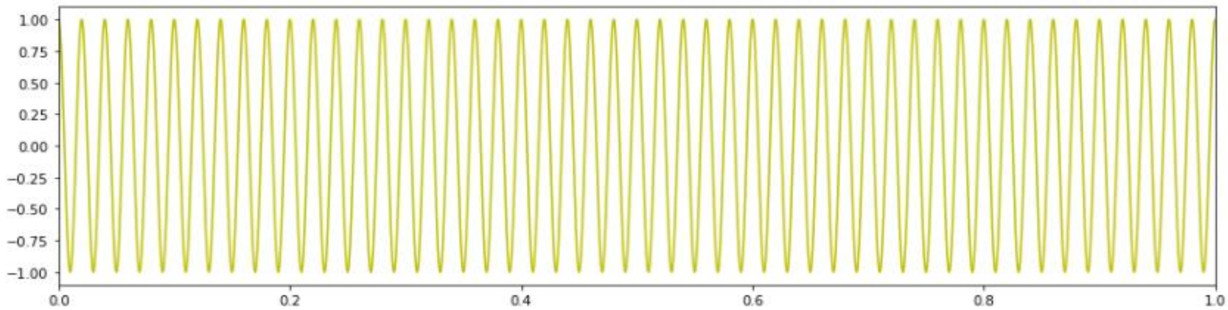


Figure 8:message signal with Fm=50

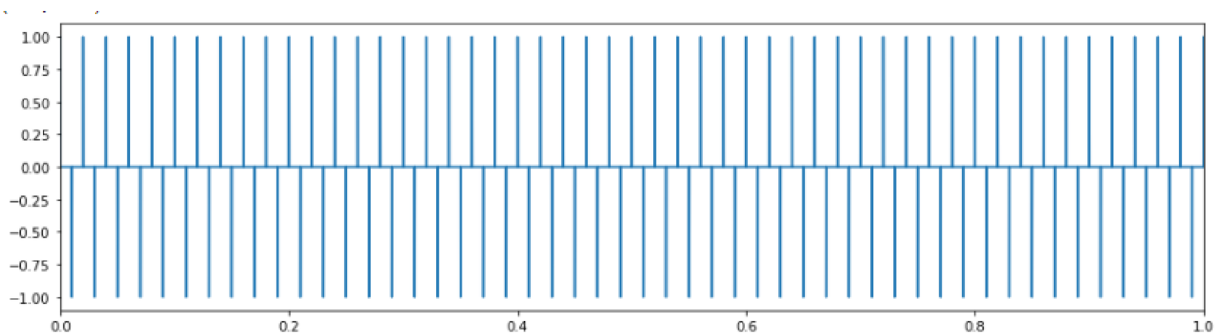


Figure 9:sampled signal with Fs=100

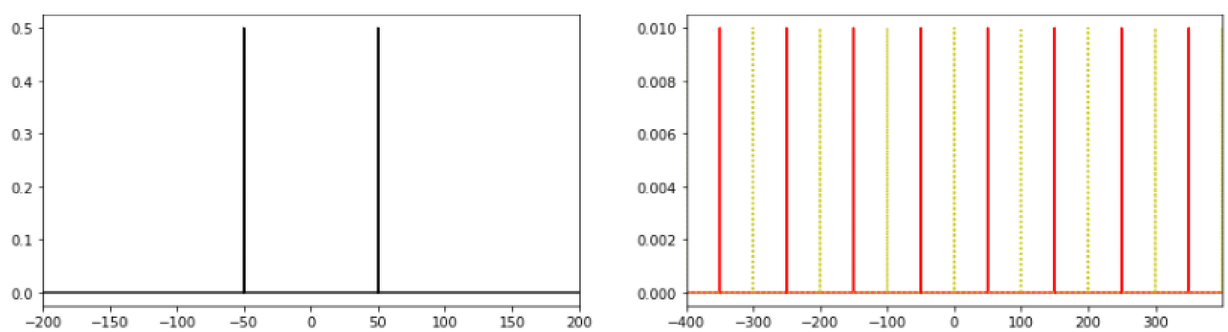


Figure 10:massage signal and convolution signal in frequency domain

- <u>**Note**</u>: In fiigure8 shows the message signal, figure9 shows the train of impulses signal, figure10 in left part show the massage signal in frequency domain but in right part show the sampled signal in red and the train of impulses that sampled on it in yellow color.

Now let’s try to reconstruct the signal using LPF with cut-off frequency = Fs/2, the results in the following:

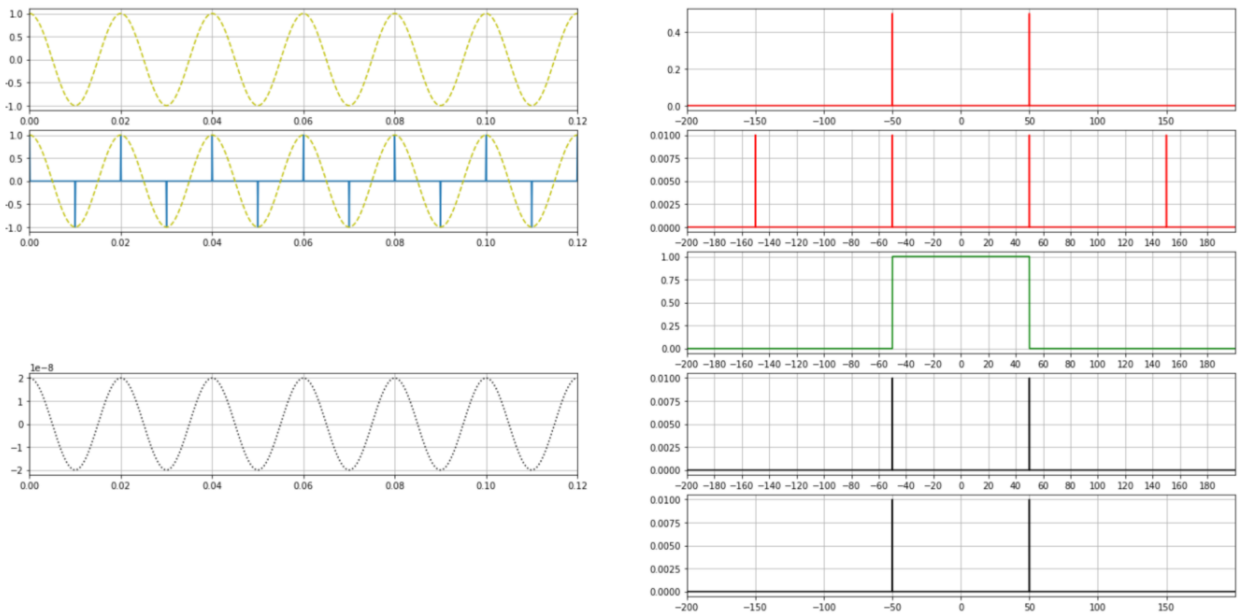


Figure 11:massage, sampling and recovered massage signal

- **<u>Note</u>:** from above figure we show two part, left part shows all the signals in time domain, the 1st plot from the top shows the message signal, then the sampled signal, then the reconstructed signal. And in the right part we show all the signal in frequency domain, the 1st plot from the top shows the message signal, then the sampled signal and in this case we notice the upper side band for the left signal (fs small) matched with lower side band for right signal (fs large), then the LPF with cut-off frequency used for reconstruct the signal so in this case we still can recovered the massage signal, then the reconstructed signal, the last plot shows the reconstructed signal zoomed-in.

Exercise:

In this case We don't want to change the value of fm and Am because if we decrease fm we will come back to previous case (fs>2fm) and we have discussed it earlier also if we increase it we will have aliasing (fs<2fm), and this situation will be discussed later also if we change the value if Am we will have discussed it and its effect will not differ in this case from the previous case. But in this case we need change the fs and show what his change affect.

1- **let change fs=102:**

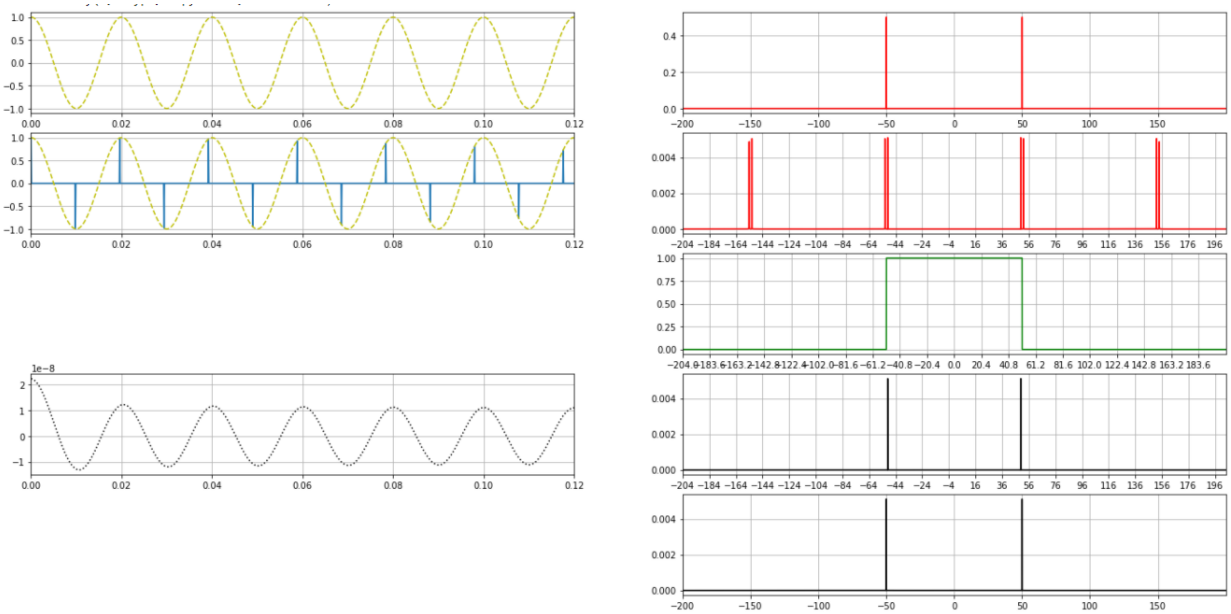


Figure 12:massage, sampling and recovered massage signal when fs=102

- **Note**: in this case when change fs=102 (fs increased) we notice:
  1- The frequency of massage signal doesn't change and the BW doesn't change because the frequency doesn't change.
  2- The frequency for sampled signal change by (fs-nfm , fs+nfm), n: integer number, also we notice when increase the value of fs the upper side band for the left signal(fs small) doesn't match with lower side band for the right signal (fs large). For example: the upper side band for fs=0[0+1*50=50] doesn't match with lower side band for fs=102[102-1*50=52] but we have some space between them.
  3- When the fs value is changed, this effect on cut-off value for LPF by fs/2 and the filter is still able to pass the Signal because fm < cut-off.
  4- Finally, we notice when the signal pass from LPF we still can recovered the massage signal.

2.1.3 **Case 3: fc < 2W(alaising):**

We will plot the message signal $m(t)$=1∗cos(2π(80)t).
fm = 80 while fs=100 which means that fs>2fm, the plots shown below.

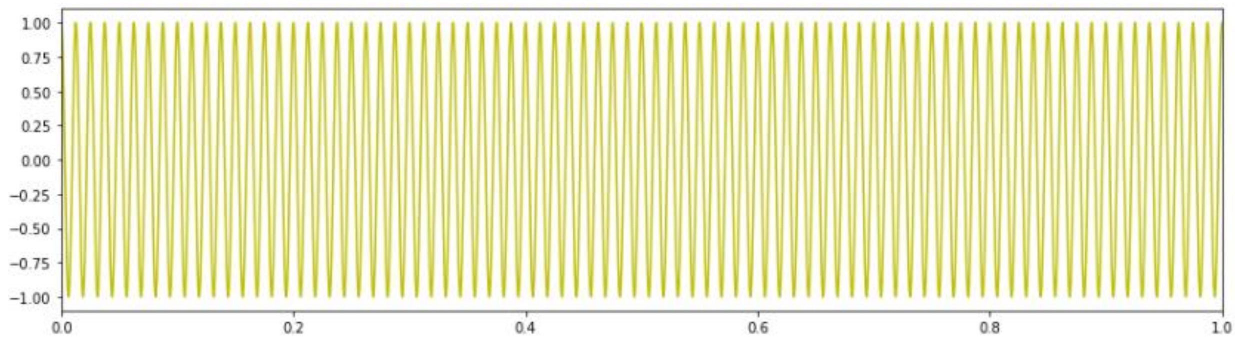


Figure 13:message signal with Fm=80

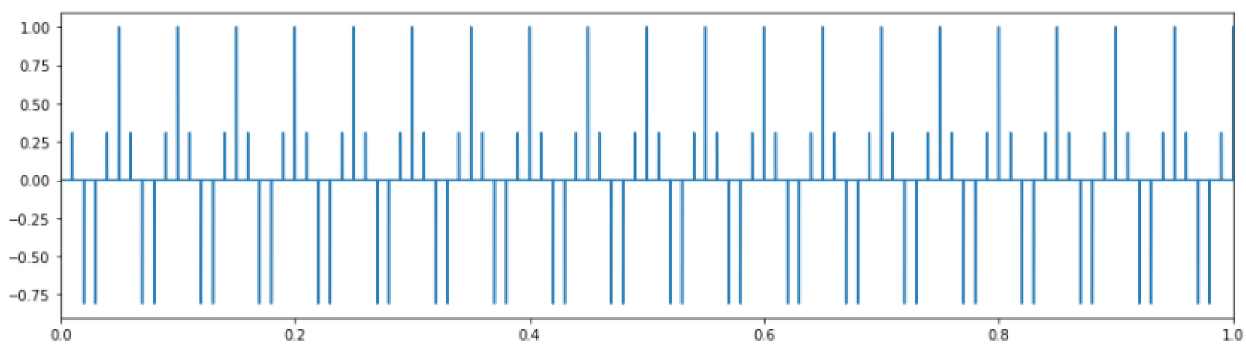


Figure 14:sampled signal with Fs=100

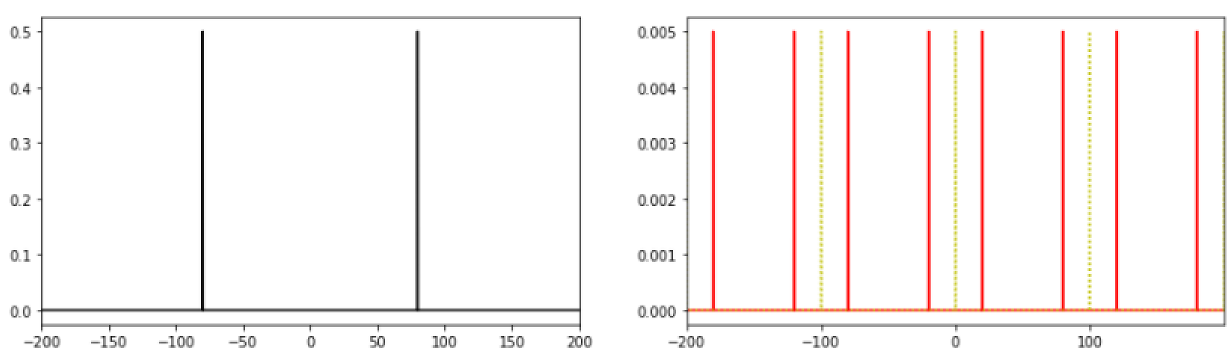


Figure 15:massage signal and convolution signal in frequency domain

- **Note**: In fiigure13 shows the message signal, figure14 shows the train of impulses signal, figure15 in left part show the massage signal in frequency domain but in right part show the sampled signal in red and the train of impulses that sampled on it in yellow color.

Now let's try to reconstruct the signal using LPF with cut-off frequency = Fs/2, the results in the following:

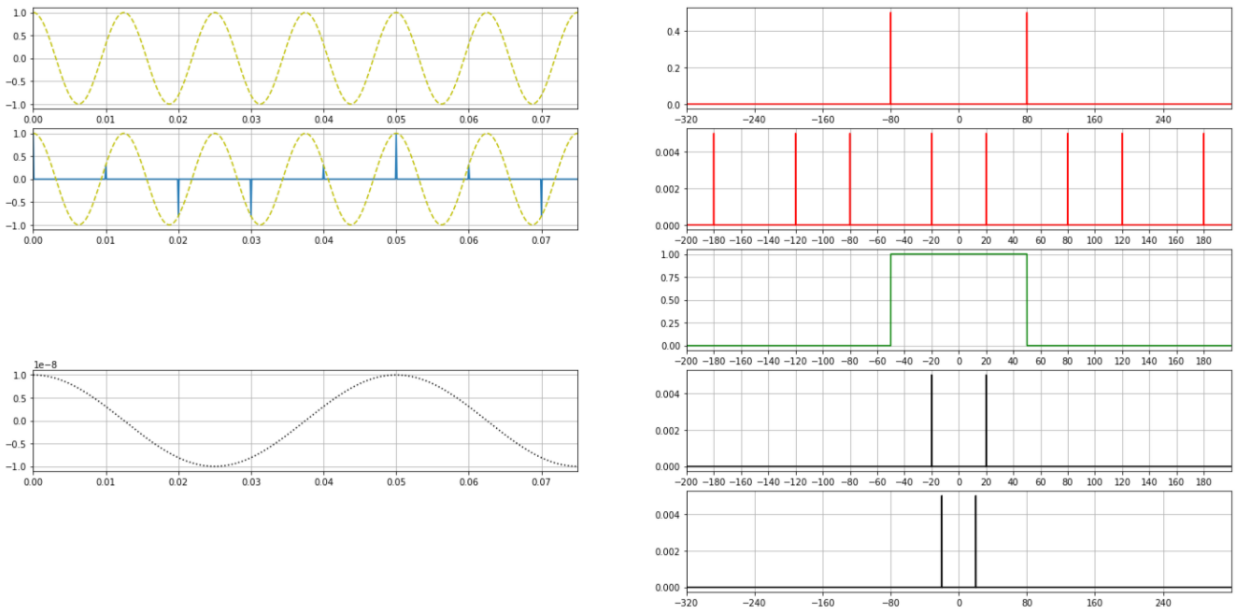


Figure 16:massage, sampling and recovered massage signal

- **<u>Note</u>**: from above figure we show two part, left part shows all the signals in time domain, the 1st plot from the top shows the message signal, then the sampled signal, then the reconstructed signal. And in the right part we show all the signal in frequency domain, the 1st plot from the top shows the message signal, then the sampled signal and in this case we notice there is an overlap between the upper side band for the left signal (fs small) with lower side band for right signal (fs large), then the LPF with cut-off frequency used for reconstruct the signal, then the reconstructed signal also in this case we can't recovered the massage signal, the last plot shows the reconstructed signal zoomed-in.

Exercise:

In this case We don't want to change the value of fs and Am because if we increase fs we will come back to previous case (fs>2fm) and we have discussed it earlier or case(fs=2fm) and we have discussed it earlier also if we change the value if Am we will have discussed it and its effect will not differ in this case from the previous case. But in this case we need change the fm and show what his change affect.

1- Let change fm=60

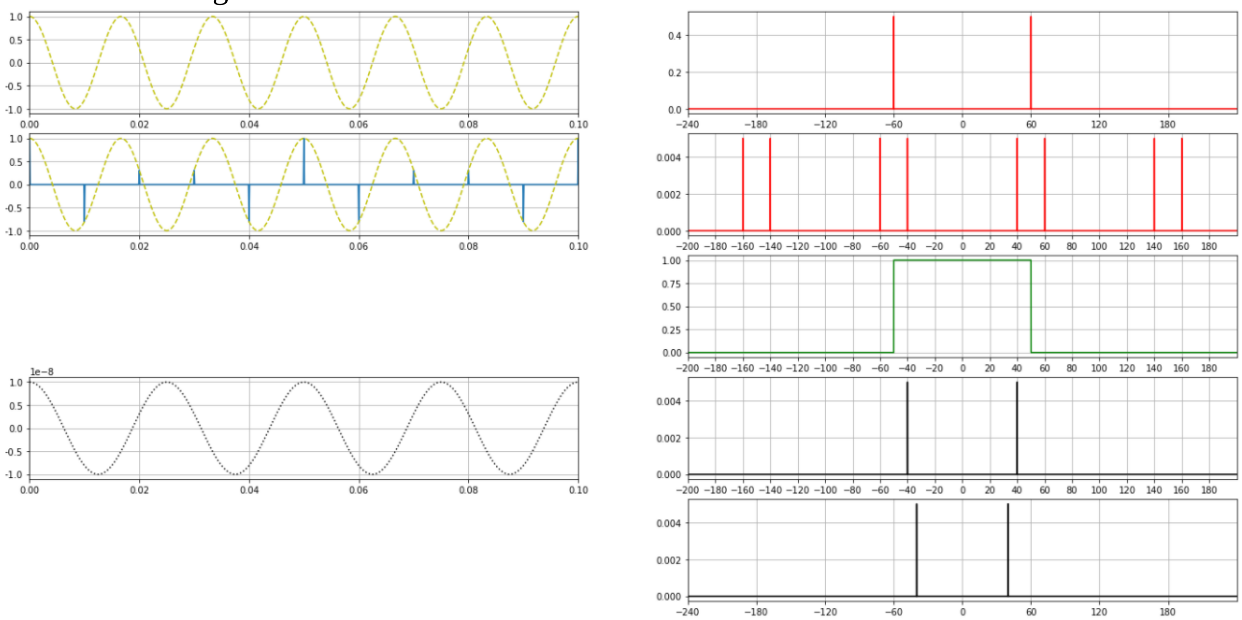


Figure 17:massage, sampling and recovered massage signal when fm=60

- **Note**: in this case when change fm=80 (fm increased) we notice:
  1- The frequency of massage signal change and moved away from each other and the BW change because the frequency change.
  2- The frequency for sampled signal change by (fs-nfm , fs+nfm), n: integer number, also we notice when increase the value of fm the upper sideband of the left signal (small fs) overlapped the lower sideband of the right signal (large fs).For example: the upper side band for fs=0[0+0*80=80] and the lower side band for fs=100 [100-1*60=40] so we notice there is an overlap between them.
  3- When the fm value is changed, this does not effect on cut-off value for LPF but in this case the filter passes the impulses have frequency (-40,40) and these impulses followed to fs=100 not fs=0.
  4- Finally, we notice when the signal pass from LPF we can’t recovered the massage signal. Where we send massage that has a fm=60, but the signal that came out of the filter has a frequency=40.

2.2 <u>Sampling of a Multitone Message Signal:</u>

Let us apply the sampling theorem to the multitone message signal $m(t)=Am1\cos(2\pi fm1t)+Am2\cos(2\pi fm2t)+Am3\cos(2\pi fm3t)$

In this part when we want to know what case we are, we make a comparison between fs with the large value for fm.

2.2.1 <u>Case 1: fs > 2W:</u>

Let fm1=20, fm2=40, fm3=60, fs=200

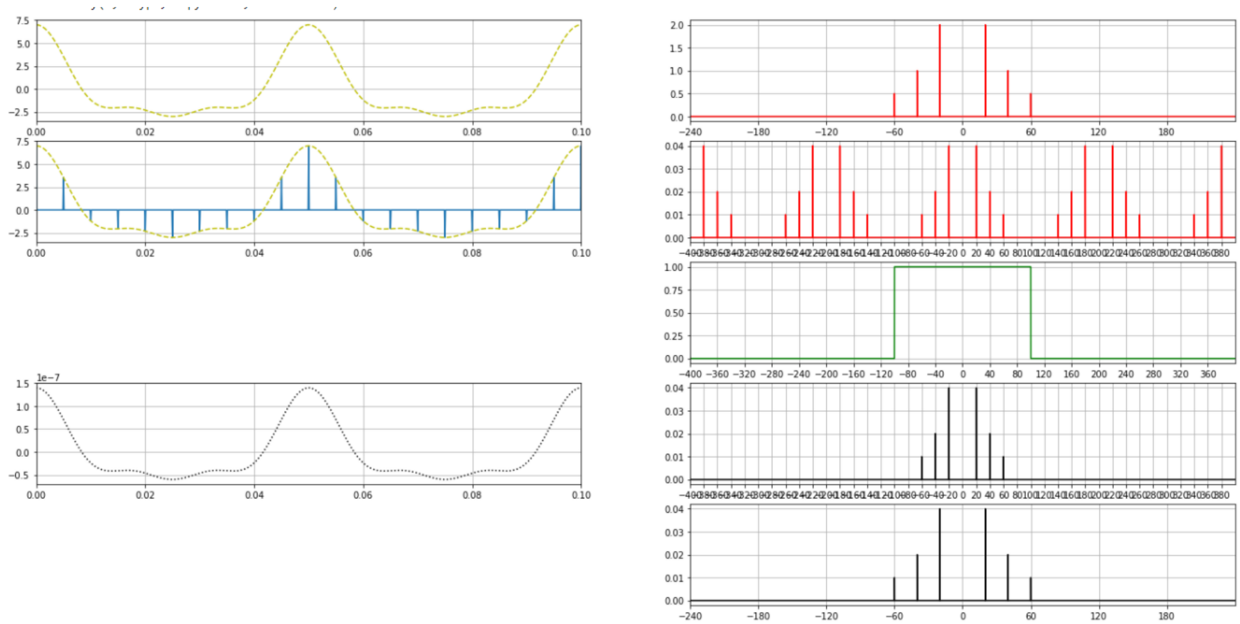


Figure 18:massage, sampling and recovered massage signal when fm1=20, fm2=40, fm3=60, fs=200

- **<u>Note</u>**: in this case fs>2fm [200>2*60] It will happen as it did in the previous part We have 6 impulses for massage frequency [(-fm1, fm1), (-fm2, fm2), (-fm3, fm3)] also the frequency for sampling changed by [(-fs-nfmk, fs+nfmk)] where n: integar number and k=1,2,3. Also in this case we can notice we have space enough space between the impulses were followed fs=0 and impulses were followed fs=200 and so on. In addition to the LPF has cut-off=fs/2 [200/2=100] where fm<cut-off so we can have recovered the massage signal. finally in this case we can recovered the massage signal.

2.2.2 **<u>Case 1: fs = 2W:</u>**

Let fm1=20, fm2=40, fm3=60, fs=120

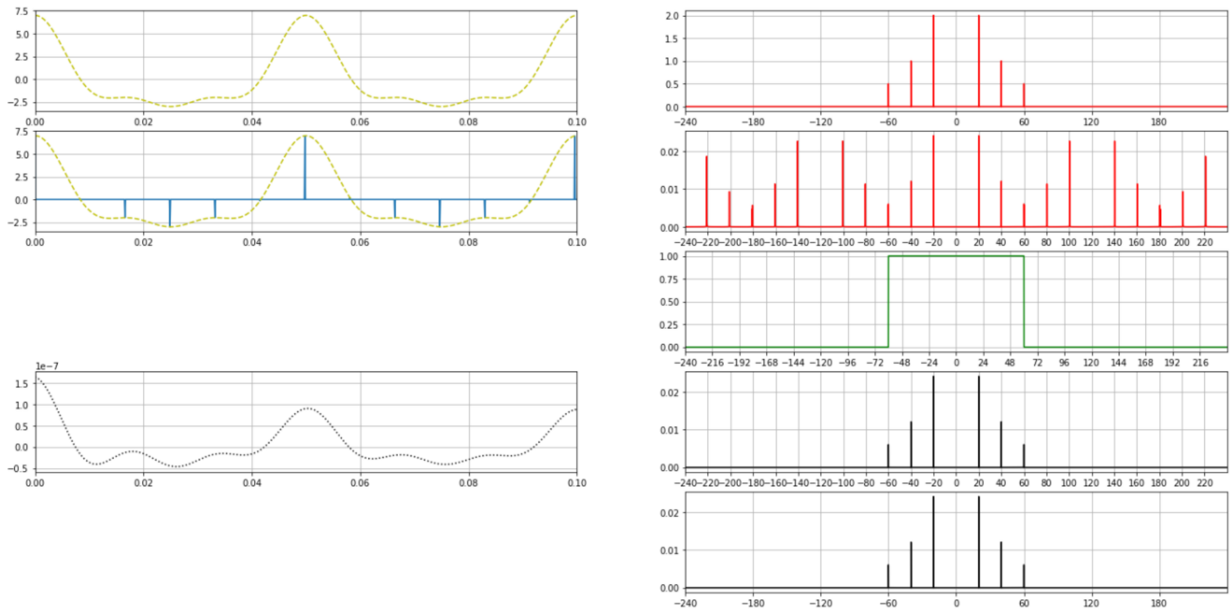


Figure 19:massage, sampling and recovered massage signal when fm1=20, fm2=40, fm3=60, fs=120

- **<u>Note</u>**: in this case fs=2fm [120=2*60] It will happen as it did in the previous part
  We have 6 impulses for massage frequency [(-fm1, fm1), (-fm2, fm2), (-fm3, fm3)]
  also the frequency for sampling changed by [(-fs-nfmk, fs+nfmk)] where n: integar number and k=1,2,3. But in this case we can notice the third upper side band impulse for fs=0 is match with the third lower side band impulse for fm=120 [(fs0+fm3)=(0+60)=60 also (fs1-fm3)=(120-60)=60] so are will matches because of that the amplitude of this impulse (impulse at g=60) being doubled because it come from two fs first one come from fs=0 and second one come from fs=120 . In addition to the signal can traverse through LPF because cut-off=fs/2 [120/2=60] where fm<=cut-off, but when this signal traverse through LPF the LPF passed the two matches impulses who are located at f=60.
  consequently, we were able to return the massage signal, but there is some attenuation that come from doubling the value the amplitude for the impulse, which is located at f=60.finally in this case we can recovered the massage signal.

2.2.3 <u>Case 1: fs = 2W:</u>

Let fm1=20, fm2=40, fm3=60, fs=100

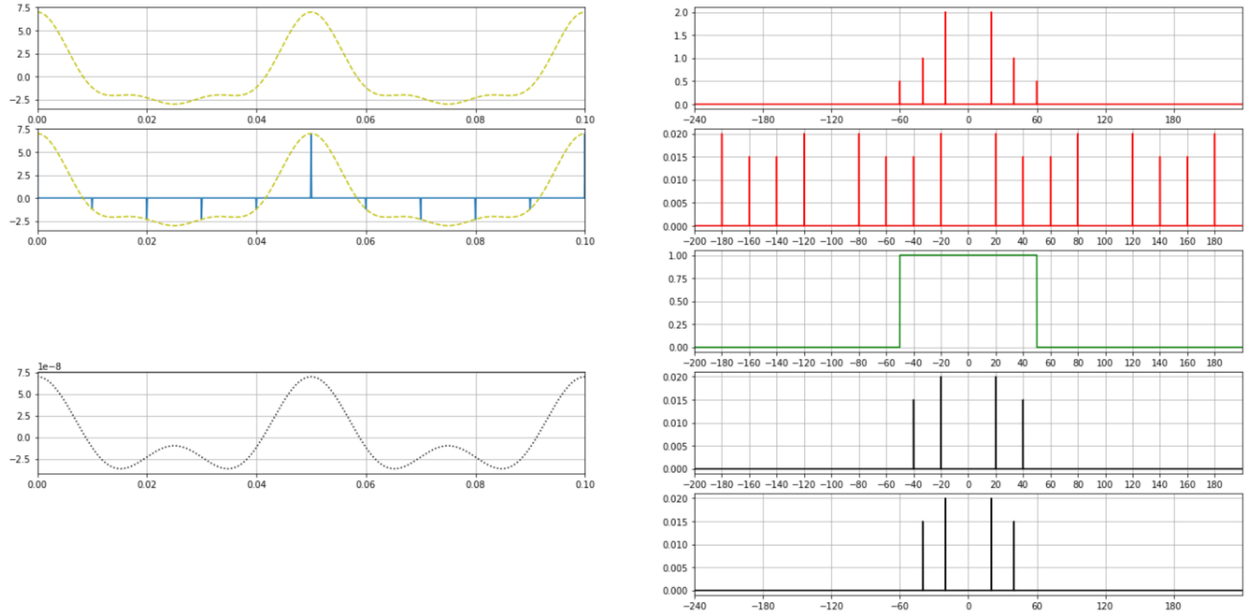


Figure 20:massage, sampling and recovered massage signal when fm1=20, fm2=40, fm3=60, fs=100

- **<u>Note</u>**: in this case fs<2fm [100 < 2*60] It will happen as it did in the previous part
  We have 6 impulses for massage frequency [(-fm1, fm1), (-fm2, fm2), (-fm3, fm3)]
  also the frequency for sampling changed by [(-fs-nfmk, fs+nfmk)] where n: integar number and k=1,2,3. But in this case we can notice the upper side band of the fs=0 overlapped the lower side band of fs=100. Consequently, when we pass the signal on the filter, the filter could not return the massage signal, but it did return the impulses that fall within the range of its [the impulses between (-fs/2) and (fs/2)] and these impulses followed fs=0 and fs=100. Finally, we notice when the signal pass from LPF we can’t recovered the massage signal. Where we send massage that has a fm1=20, fm2=40, fm3=60, but the massage that came out of the filter has a frequency= [(-20,20) and (-40,40)].

2.3 <u>Time Division Multiplexing:</u>

Time-division multiplexing (**TDM**) is a method of transmitting and receiving independent signals over a common signal path by means of synchronized switches at each end of the transmission line so that each signal appears on the line only a fraction of time in an alternating pattern, here we divide the time.

First of all, let's multiplex two signals, one of them is cosine signal with amp=1 and frequency=1, and the other is constant with amp=1 all sampled at Fs=100. The plots below show this.

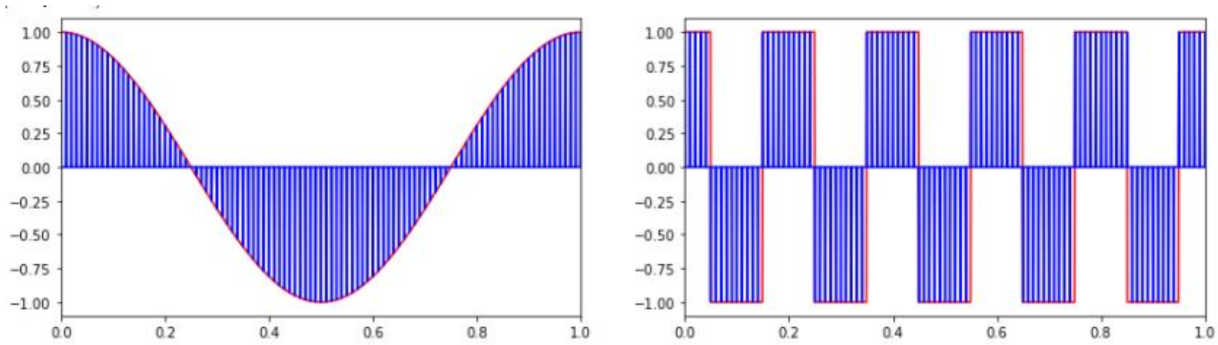


Figure 21:m1(t)=cos(2π(1)t) and m2(t)=1

- **<u>Note</u>**: from above figure we show two signals first one is cos signal in (red colure) and his impulses in (blue colure) and the second one is square signal in (red colure) and his impulses in (blue colure).

Let us try to multiplex the two above signals and plot the results below:

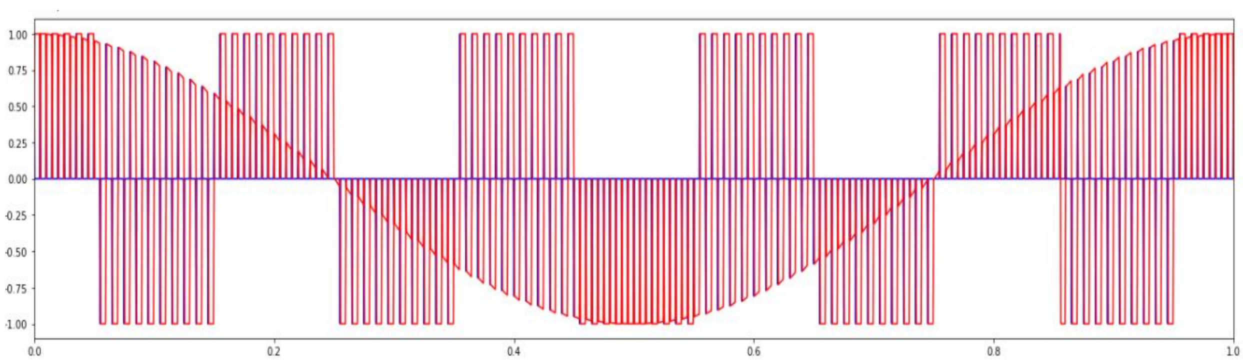


Figure 22:multiplexed the two signals

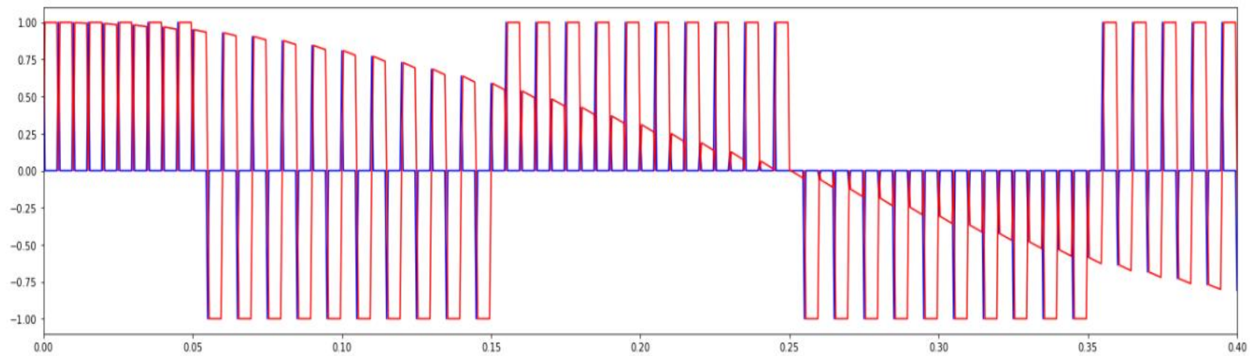


Figure 23:multiplexed the two signals zoomed-in

- **<u>Note</u>**: We can see from figure22 and figure 23 that each independent signal appears in fraction of time while the other is off, where the signals are sent respectively once Cos signal and once Square signal. In order to recovered the original massage of each signal, we must separate the pulses for two signal from each other and then insert them on the Low Pass Filter.

<u>Exercise</u>:

1- <u>Let change fm=3:</u>

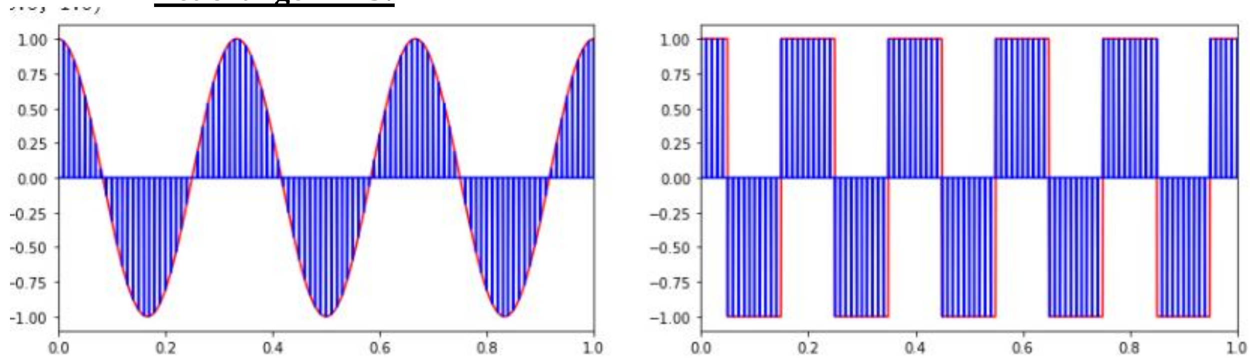


Figure 24:m1(t)=cos(2π(1)t) and m2(t)=1 when fm=3

- **<u>Note:</u>** we can show when increase fm this effects on the value of the period of the cos signal and affects the value of the BW, where when the value of fm change the period of the signal decreased by 1/fm and the pluses are close to each other, while change fm it causes a difference in the period of the multiplexed signal and this different due to the difference of the cos signal periodic. But multiplexing process it will stay each indication appears independent at a fraction of the time while the other is off and that appears in the figure below.

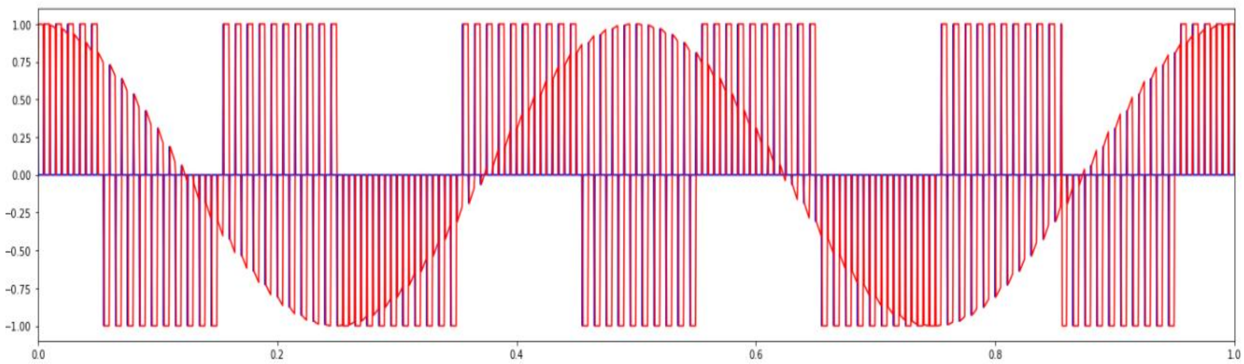


Figure 25:multiplexed the two signals when fm=3

2- <u>Let change du=0.3:</u>

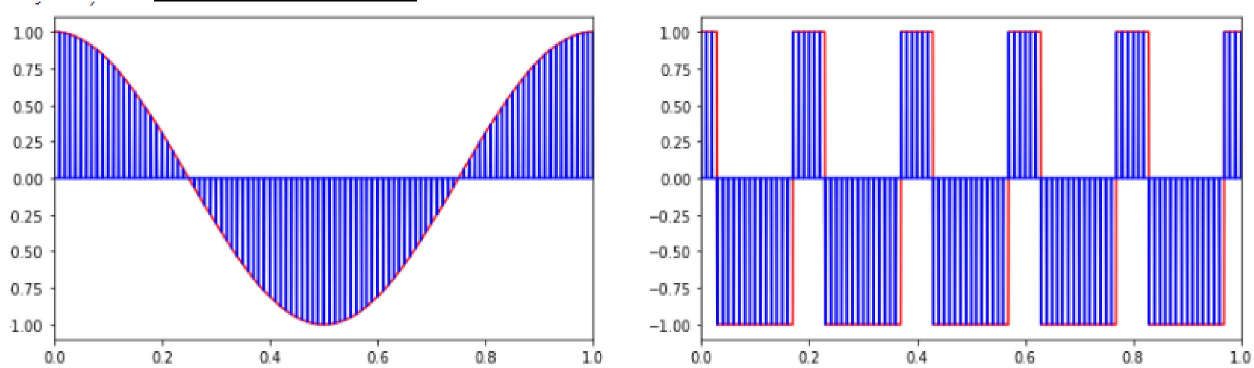


Figure 26:m1(t)=cos(2π(1)t) and m2(t)=1 when du=0.3

- **<u>Note:</u>** we can show when decreased du, this effects on period of (ON and OFF) for square signal, so in this case the allocated period when the square signal ON will be decreased. While change du does not effect on multiplexed process, where it will stay each indication appears independent at a fraction of the time while the other is off and that appears in the figure below.

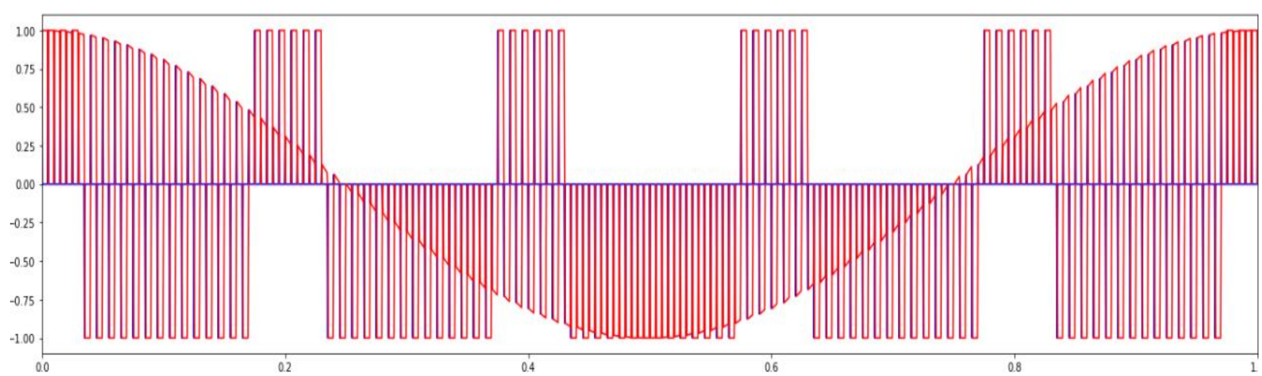


Figure 27:multiplexed the two signals when du=0.3

Now let take another example we will time-multiplex two single tone signals (cos and sin).

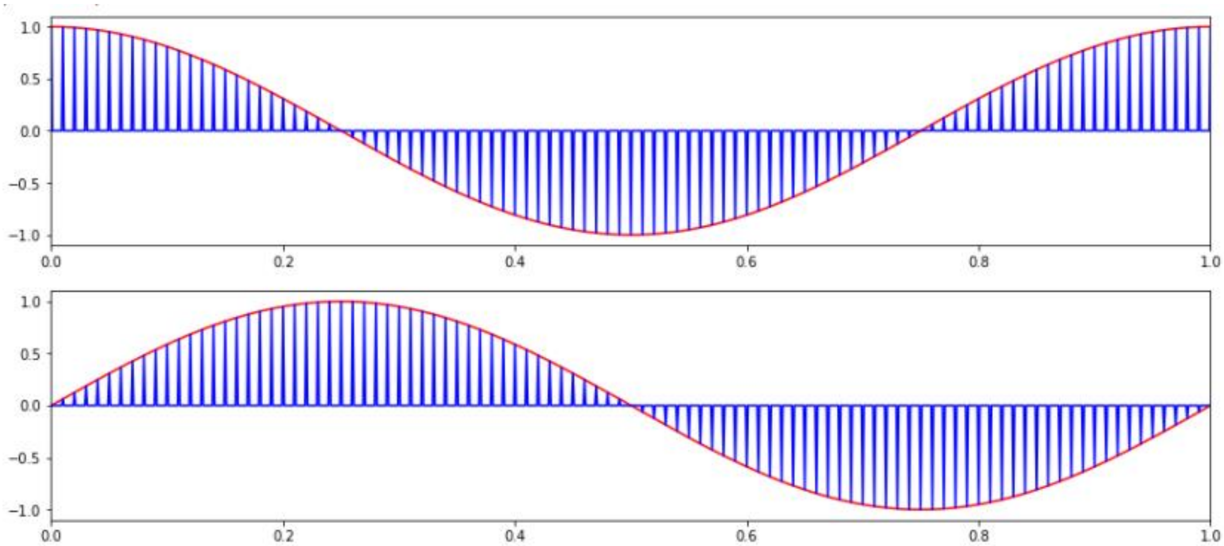


Figure 28:m1(t)=cos(t) and m2(t)=sin(t)

- **Note**: from above figure we show two signals first one is cos signal in (red colure) and his impulses in (blue colure) and the second one is sin signal in (red colure) and his impulses in (blue colure).

Let us try to multiplex the two above signals and plot the results below:

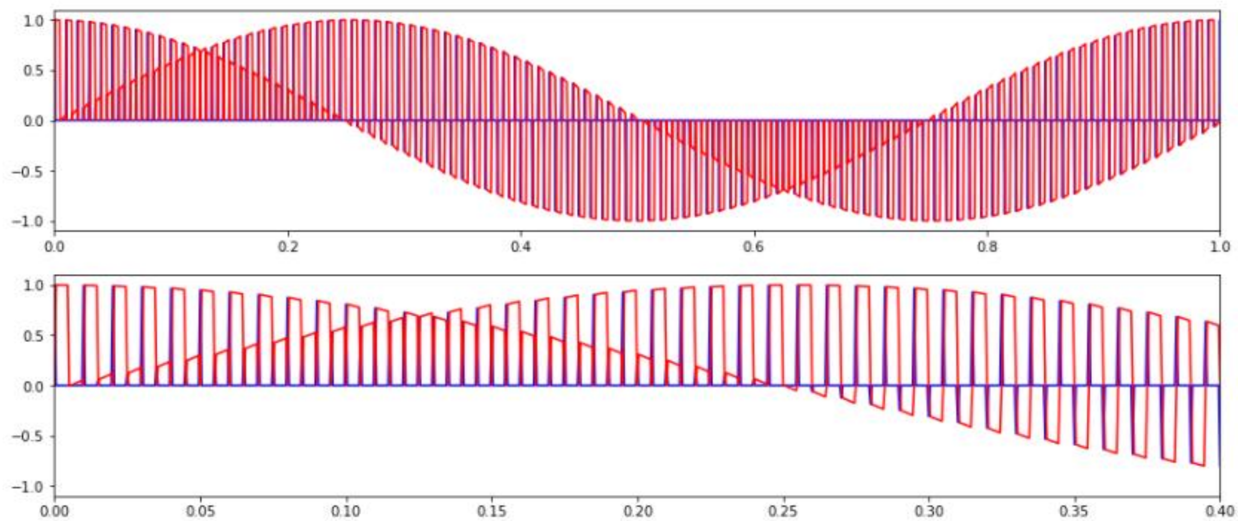


Figure 29:multiplexed the two signals and zoomed-in

- **Note**: We can see from figure29 that each independent signal appears in fraction of time while the other is off, where the signals are sent respectively once Cos signal and once Sin signal. In order to recovered the original massage of each signal, we must separate the pulses for two signal from each other and then insert them on the Low Pass Filter.

Exercise:

3- **Let change fm=3:**

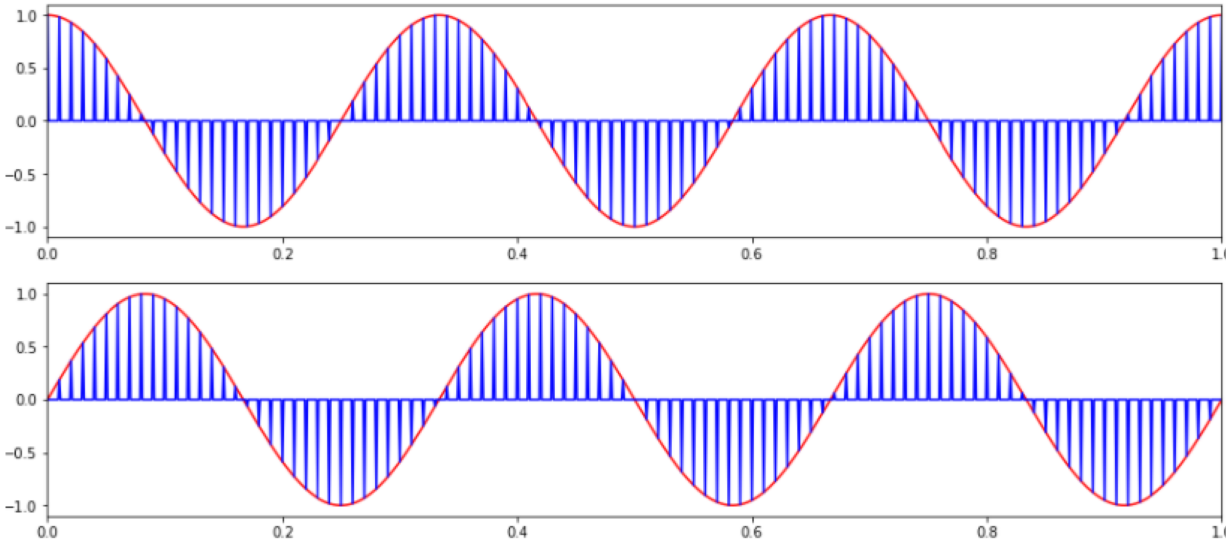


Figure 30:m1(t)=cos(t) and m2(t)=sin(t) when fm=3

- **Note:** we can show when increase fm this effects on the value of the period of the cos and sin signals and affects the value of the BW, where when the value of fm change the period of the signal decreased by 1/fm and the pluses are close to each other. While change fm it causes a difference in the period of the multiplexed signal and this different due to the difference of the cos and sin signals periodic. But multiplexing process it will stay each indication appears independent at a fraction of the time while the other is off and that appears in the figure below.

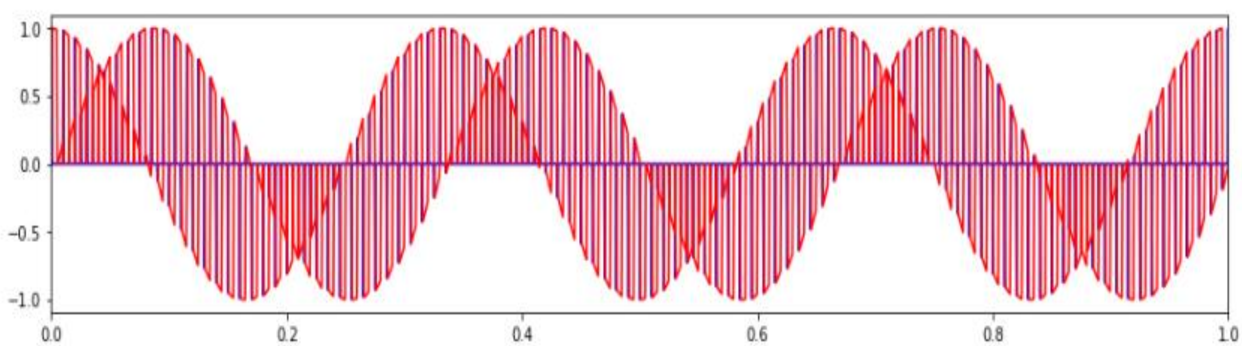


Figure 31:multiplexed the two signals when fm=3

3. Conclusion:

In conclusion, we were able to understand the Working mechanism of Pulse Amplitude Modulation and understand the different between another type of sampling theorem where the sampling theorem specifies the minimum-sampling rate at which a continuous-time signal needs to be uniformly sampled so that the original signal can be completely reconstructed by these samples alone. We conclude from all the results shown above that when Fs >= 2W case1 and case3 it's satisfy Nyquist rate so we could reconstruct the message signal by applying a LPF with cut-off frequency = Fs/2, but when Fs<2W in case3 it doesn't satisfy the Nyquist rate so we could not recover or reconstruct the message signal. Also, we were able to understand the division multiplexing proses and effect of changing the parameters on the multiplexing signal. Finally, the experiment ran smoothly using the Colab and our results were logical and convincing.