Faculty of Engineering and Technology

Electrical and Computer Engineering Department

Communications Lab – ENEE4113

Report #: 1

Experiment #: 1

Experiment Title: Normal Amplitude Modulation and Demodulation

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Section #: 2

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Abstract

This experiment aims to connect theoretical knowledge of Normal Amplitude Modulation to practical application, through communication Lab kits and the Cassy Lab software. This experiment aims to understand the Normal Amplitude Modulation process, including signal generation, filter effects, and the impact of changing the message signal (modulating signal) parameters on the modulated signal, additionally, it aims to understand the Coherent and Non-Coherent Demodulation process, and compare the results obtained in time and frequency domains.

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Theory

1. Modulation- Definition and Types

Modulation is how to change a carrier signal's features to match a message signal.

This process helps data travel over long distances.

Message Signal (modulating signal m(t)): Represents the original data wanted to be sent.

Carrier Signal (c(t)): Represents high-frequency signal that carries the message signal.

Result (modulated signal s(t)): Combination of both signals for improved data transfer. [1]

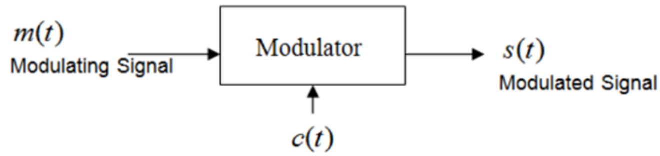

Figure 1: Modulation Process - block diagram [2]

2. Modulation Types

1. Amplitude Modulation.

2. Frequency Modulation.

3. Phase Modulation. [2]

Types of Amplitude Modulation

Amplitude Modulation is a type of modulation in which the carrier signal's amplitude changes in proportion to the message signal while keeping phase and frequency constant. [3]

1. Normal Amplitude Modulation

2. Double Sideband Suppressed Carrier Modulation

3. Single Sideband Modulation

4. Vestigial Sideband Modulation. [1]

4. Normal Amplitude Modulation

A Normal Amplitude Modulation is defined as:

$$s(t) = A_C\big(1 + k_a m(t)\big)\cos(2\pi f_C t)$$

Equation 1: Normal Amplitude modulation form1

Where:

1.$s(t)$: The modulated Signal, represents the result of the modulation

2.$m(t)$: the Message signal (also called the modulating Signal)

3.ka: The sensitivity of the AM modulator

4.AC: Amplitude of the carrier Signal.

5.fC: Frequency of the carrier Signal. [1]

S(t) can be written also in this form:

$$s(t) = A(t)\cos(2\pi f_C t)$$

Equation 2: Normal Amplitude modulation form

Where A(t) is the envelope of s(t) and it is $AC|1+kam(t)|$. [3]

5. Spectrum of the Normal Amplitude Modulation

Consider Equation 2 which is the equation of Normal Amplitude Modulation in the time domain

The Fourier Transform of it will be:

$$S(f) = \frac{A_c}{2}\delta(f - f_c) + \frac{A_c}{2}\delta(f + f_c) + \frac{A_c k_a}{2}M(f - f_c) + \frac{A_c k_a}{2}M(f + f_c)$$

Equation 3: Spectrum of the Normal Amplitude Modulation. [3]

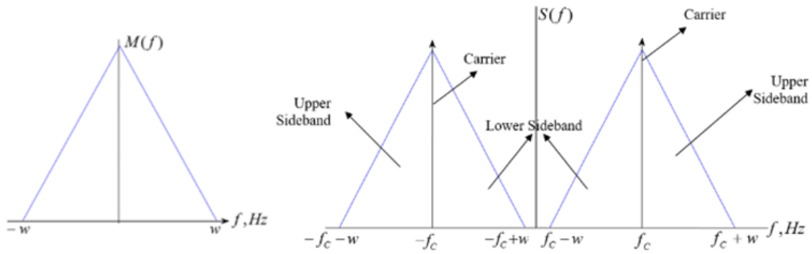

Figure 2: Spectrum of the message signal (modulating signal) M(f) and the modulated signal S(f). [3]

Consider Figure 2, the spectrum of the message signal M(f) has been shifted to a new position around the carrier frequency fc. The spectrum of the modulated signal S(t) has two sidebands (upper sideband and lower sideband) and the carrier in the middle.[3]

The space needed to send the signal is found by doubling the width of the message signal and covering both sides of the carrier frequency.[3]

$$\mathbf{B \cdot W = 2Fm}$$

Equation 4: Normal AM Band Width. [3]

Where:

1. **B.W**: is the transmission bandwidth which represents the space needed to send the signal.

2. **Fm:** is the message signal bandwidth.

6. Demodulation

The demodulation is the process of getting back the message signal from the modulated signal.[3]

6.1.Coherent Demodulation

Consider below Figure 3 that shows the coherent demodulation process, c'(t) represents a signal that looks like the carrier signal, which is multiplied by the modulated signal s(t), to get back the original message signal. [4]

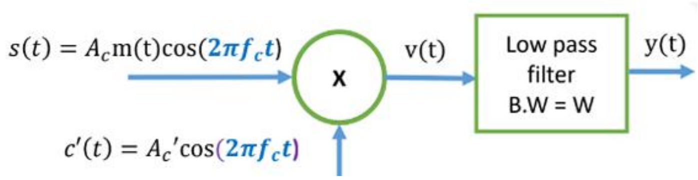

Figure 3: Coherent Demodulation Block Diagram [3]

6.2.Non-Coherent Demodulation

Consider Figure 4 which shows the coherent demodulation process, c'(t) represents a signal that looks like the carrier signal but with a phase shift. This signal is multiplied by the modulated signal s(t), to get back the original message signal. [4]

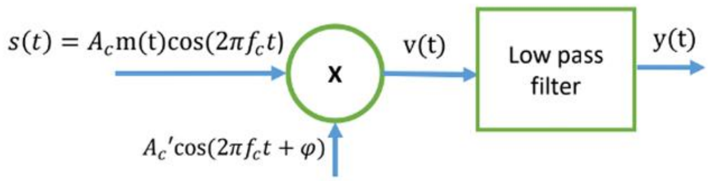

Figure 4: Non-Coherent Demodulation Block Diagram [3]

Procedure

We connected the transmitter, receiver, and function generator with the DC power supply using Jumpers, so we connected the +15V and the -15V and zero, and then we turned the kit on to start the experiment (we have done the initial connections before starting any part).

1. Part One: Normal Amplitude Modulation

1.1. Message Signal

To generate the message signal of the Normal AM, we set the function generator with these parameters:

1. Message signal type: sinusoidal

2. VSS (V peek-to-peek) = 4 V

3. Frequency fm = 2kHz

We have connected this message signal on the UA1 channel in the Cassy sensor and then we opened the Cassy Lab software and set the required settings (Like 2.5ms since we want 5 cycles) and then run it to see the message signal in the time and frequency domain.

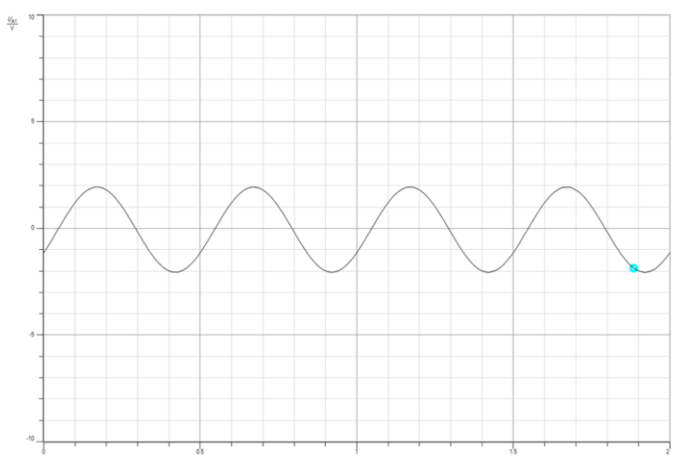

Figure 5: Message Signal with Vss=4V and fm=2KHz in Time domain

Consider Figure 5, we can see that the amplitude in voltages in the y-axis, so the amplitude of the signal in the figure is 2Volt, and that is true since:

$$v_{ss} = 2v_m$$

Where Vss is the peek-to-peek voltage and Vm is the message voltage.

In our case Vss = 4 volt

$$4volt = 2v_m$$

$$v_m = 2\ volt$$

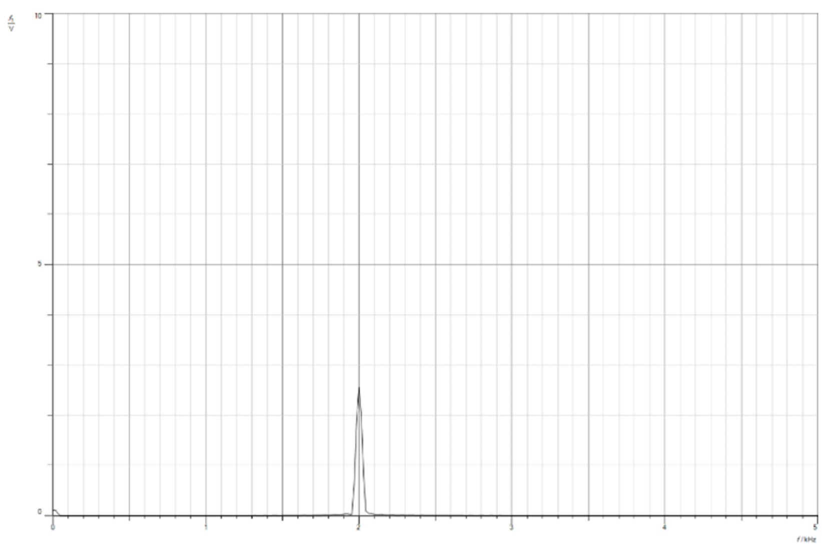

Figure 6: Message Signal with Vss=4V and fm=2KHz in Frequency domain

Consider Figure 6, the frequency in kHz in the x-axis, so the frequency of the signal in the figure is 2 kHz, and that is true according to the frequency we have set in the function generator.

1.2. Carrier Signal

We connected the frequency oscillator (which generates the carrier by fc =160) by doing that we got the carrier signal so we connected it to the UB1 channel in the Cassy sensor and then we opened the Cassy Lab software and we set the required settings then run it to see the message signal in time and frequency domain. The carrier is generated using a pulse frequency oscillator of 160 kHz, after that this 160 kHz will be entered to a frequency division block, in our kit it divide the carrier frequency by 10. So it will result in fc = 16 kHz. Consider Figure 7, the frequency in kHz in the x-axis, so the frequency of the signal in the figure is 16 kHz, so the result is true.

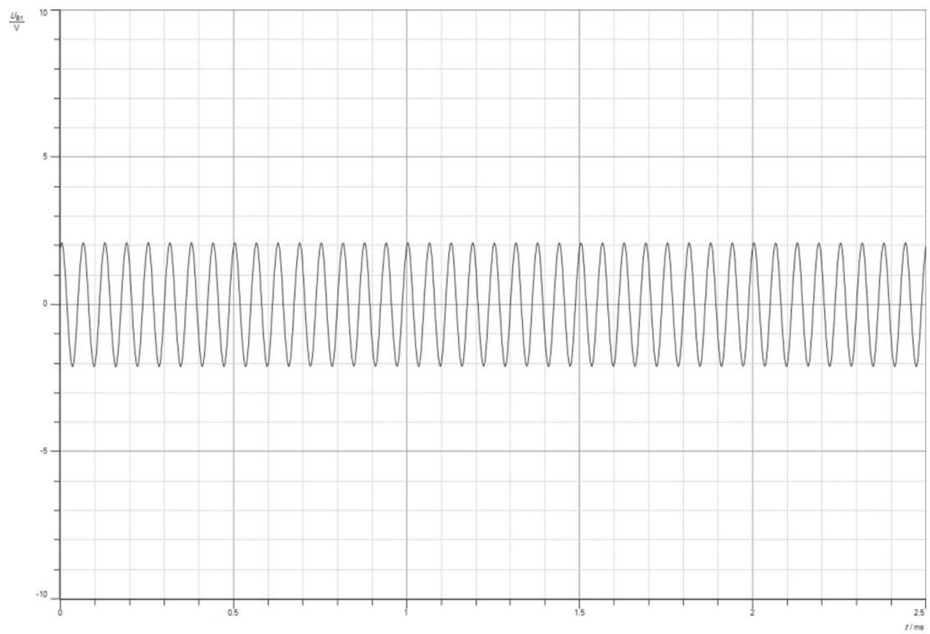

Figure 7: Carrier signal - Time domain

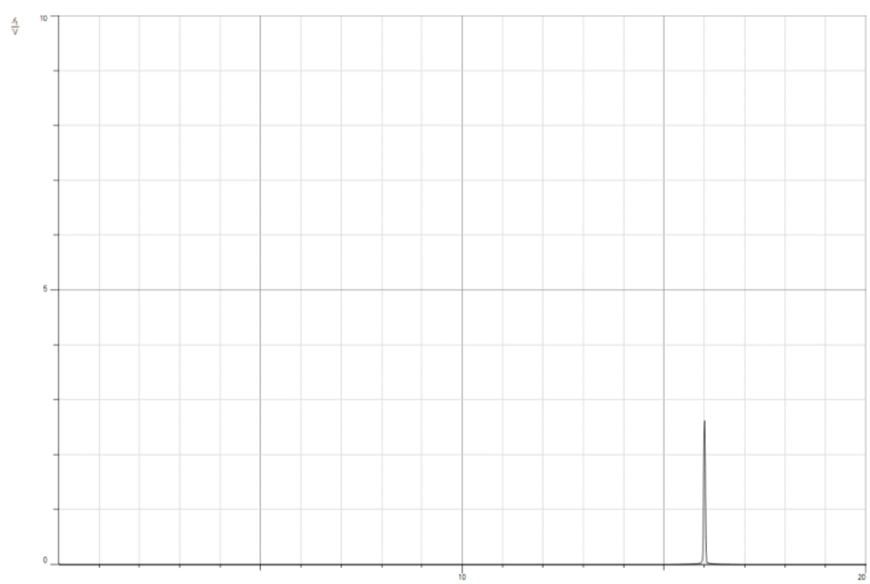

Figure 8: Carrier signal - Frequency domain

The Carrier Amplitude according to the Cassy Lab results is approximately 2, so:

Carrier amplitude Ac = 2 volt

Carrier Frequency Fc = 16 kHz

1.3. Modulated Signal

We have connected the blocks as shown in Figure 9, we connected the message signal and the carrier to the multiply block, and we set the toggle switch to Carrier ON because this represents the sum of the carrier after multiplication of the message signal and the carrier to generate the modulated signal:

$$s(t) = A_C\big(1 + k_a m(t)\big)\,cos(2\pi f_C t) = c(t) + km(t)c(t)$$

So when the toggle switch is to Carrier ON it will add the carrier, and since we are doing Normal Amplitude Modulation we need it ON.

Then we connected the message signal on the UA1 channel and the modulated signal on channel UB1, then we opened the Cassy Lab software and set the required settings then ran it to see the message signal in the time and frequency domain.

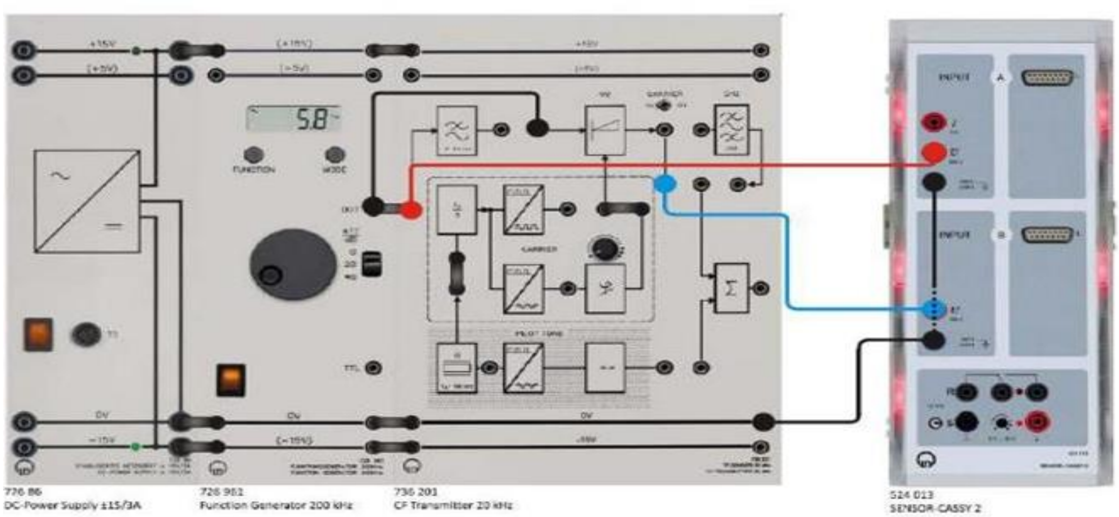

Figure 9: Modulated Signal - Toolkit connections

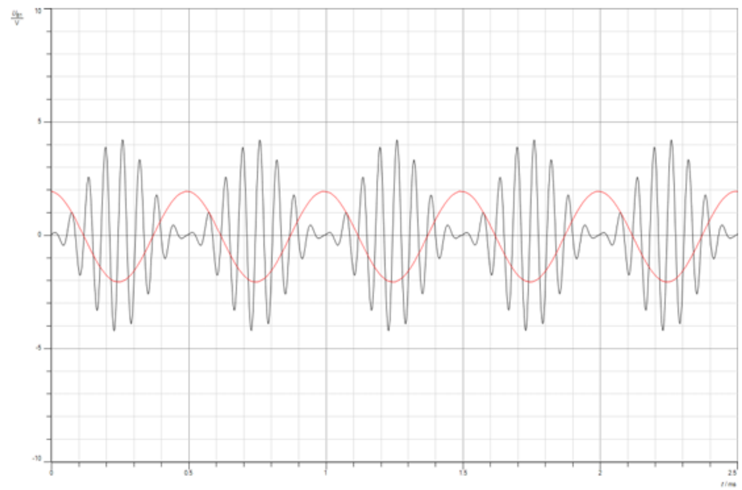

Figure 10: Modulated Signal S(t) - Time Domain

Consider Figure 10, the message signal is in red and the modulated signal is in black. So it has an amplitude = 2 and that is true since:

$$s(t) = A_C\big(1 + k_a m(t)\big)\cos(2\pi f_C t)$$

$$k_a = \frac{\mu}{Am}$$

So we should find the modulation index.

Amax = 4 , Amin = 0

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

According to the shape in the figure Amax = 4 and Amin = 0

$$\mu = \frac{4-0}{4+0} = 1$$ (M=1 Normal Modulation)

To find the modulator sensitivity Ka:

$$\text{Ka} = \frac{\mu}{Am} = \frac{1}{2} = 0.5\,volt^{-1}.$$

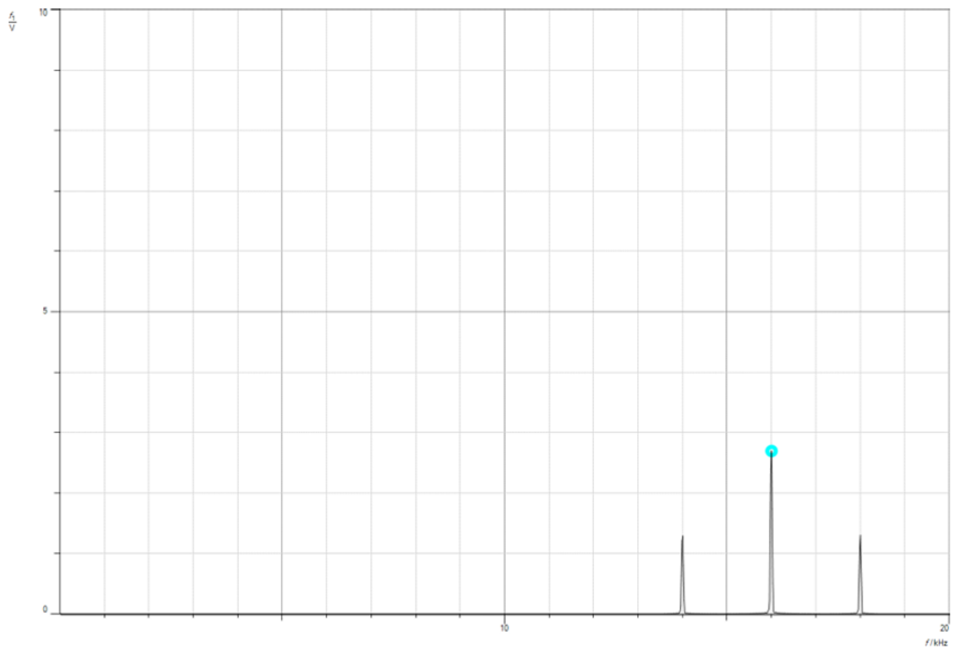

Figure 11: Modulated Signal S(t) - Frequency Domain

Consider Figure 11, it shows the S(f) which consists of the two sidebands (upper and lower) the upper with 18 kHz which is true since the upper sideband frequency should be fc + fm = 16 kHz + 2kHz = 18kHz also the lower sideband is 14 kHz and the carrier with fc = 16 kHz is a the true result since the spectrum of the modulated signal after applying the Fourier Transform

The modulated signal should be:

$$S(f) = \frac{A_c}{2}\delta(f - f_c) + \frac{A_c}{2}\delta(f + f_c) + \frac{A_c k_a}{2}M(f - f_c) + \frac{A_c k_a}{2}M(f + f_c)$$

$$S(f) = \delta(f - 16000) + \delta(f + 16000) + 0.5\delta(f - 18000) + 0.5\delta(f + 18000) + 0.5\delta(f - 14000) + 0.5\delta(f + 14000)$$

So the spectrum of the modulated signal is represented as 3 impulses on the positive side, one on 16kHz is the carrier, on 14kHz which is the lower side band, and on 18kHz which is the upper sideband, so the Cassy Lab software result is true.

The bandwidth of the modulated signal is 18kHz – 14kHz = 4kHz which is also true since B.W

= 2Fm = 2×2 = 4kHz. Where B.W is the transmission bandwidth, and W is the message signal bandwidth.

To find the power efficiency:

$$\eta = \frac{\mu^2}{2+\mu^2} = \frac{1}{2+1} = \frac{1}{3} = 0.33 = 33\%$$

1.4.The effect of varying the frequency (FM)

a. Vss = 4 Volt, Change fm to 1kHz

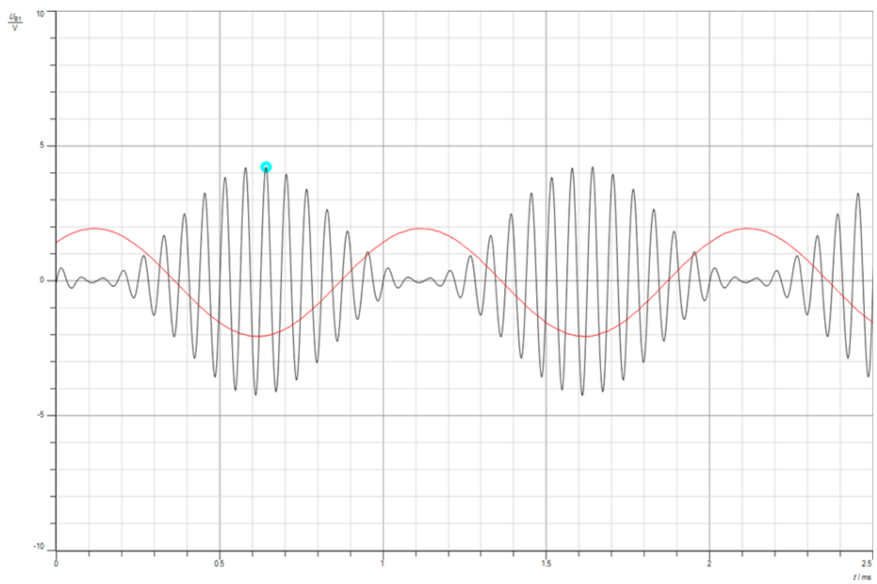

Figure 12: vss=4v, fm = 1kHz - time domain

Consider Figure 12, the message signal is in red and the modulated signal is in black. To find the modulation index, So we should find the modulation index.

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

According to the shape in the figure Amax = 4 and Amin = 0

$$\mu = \frac{4-0}{4+0} = 1$$

No changes happened on the modulation index due to the change of the frequency that we did also, the amplitude of the signal remains the same. And that is a true result since:

$$s(t) = A_c\big(1 + k_a m(t)\big)\,cos(2\pi f_c t)$$

$$k_a = \frac{\mu}{Am}$$

To find the modulator sensitivity Ka:

$$\text{Ka} = \frac{\mu}{Am} = \frac{1}{2} = 0.5\,volt^{-1}.$$

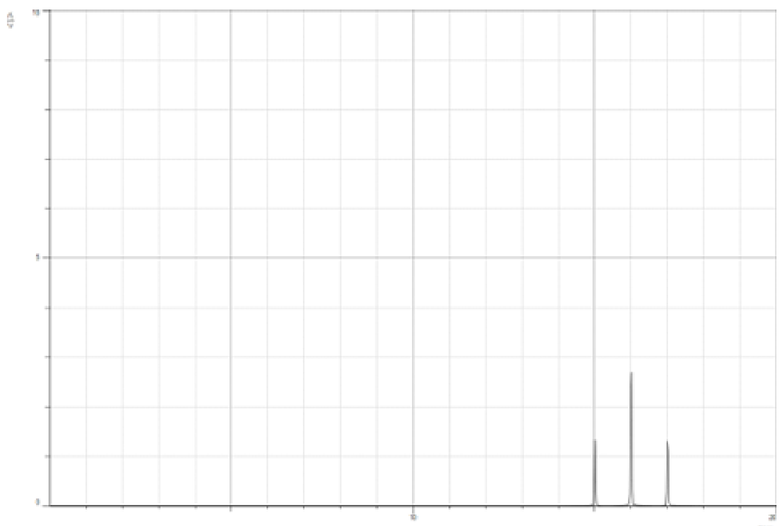

Figure 13: vss=4v, fm = 1kHz - frequency domain

Consider Figure 13, which shows the S(f) which consists of the two sidebands (upper and lower) the upper with 17 kHz, the lower sideband is 15 kHz, and the carrier with fc = 16 kHz. That is a true result since the spectrum of the modulated signal after applying the Fourier Transform on the modulated signal should be:

$$S(f) = \frac{A_c}{2}\delta(f - f_c) + \frac{A_c}{2}\delta(f + f_c) + \frac{A_c k_a}{2}M(f - f_c) + \frac{A_c k_a}{2}M(f + f_c)$$

$$S(f) = \delta(f - 16000) + \delta(f + 16000) + 0.5\delta(f - 17000) + 0.5\delta(f + 17000) + 0.5\delta(f - 15000) + 0.5\delta(f + 15000)$$

So the spectrum of the modulated signal is represented as 3 impulses on the positive side, one on 16kHz which is the carrier, one on 15kHz which is the lower side band, and one on 17kHz which is the upper sideband, so the Cassy Lab software result is true. So the change of the frequency affects the upper and lower sidebands. The band width is 17kHz – 15kHz = 2kHz which is also true since B.W = 2Fm = 2×1 = 2kHz. Where B.W is the transmission bandwidth, and W is the message signal bandwidth. So the change of the frequency also affects the B.W of the modulated signal, and that is logical since the B.W of the modulated signal has a direct relation with the bandwidth of the message signal (which is the frequency of the message signal fm), so when we reduce the frequency of the message signal to 1kHz the bandwidth of the modulated reduced to 2kHz.

To find the power efficiency:

$$\eta = \frac{\mu^2}{2+\mu^2} = \frac{1}{2+1} = \frac{1}{3} = 0.33 = 33\%$$

b. Vss = 4 Volt , Change fm to 3kHz

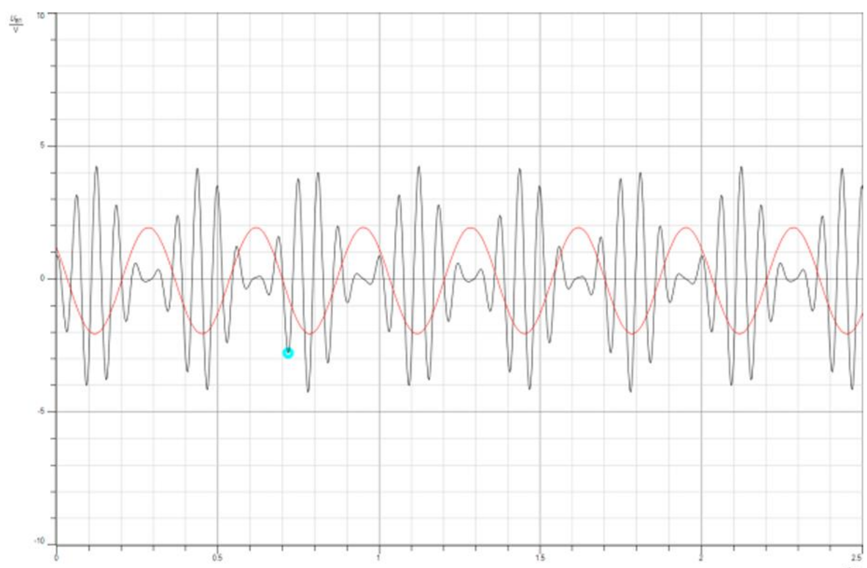

Figure 14: vss=4v, fm = 3kHz - time domain

μ = 1 No changes happened on the modulation index due to the change of the frequency that we did also the amplitude of the signal remains the same.

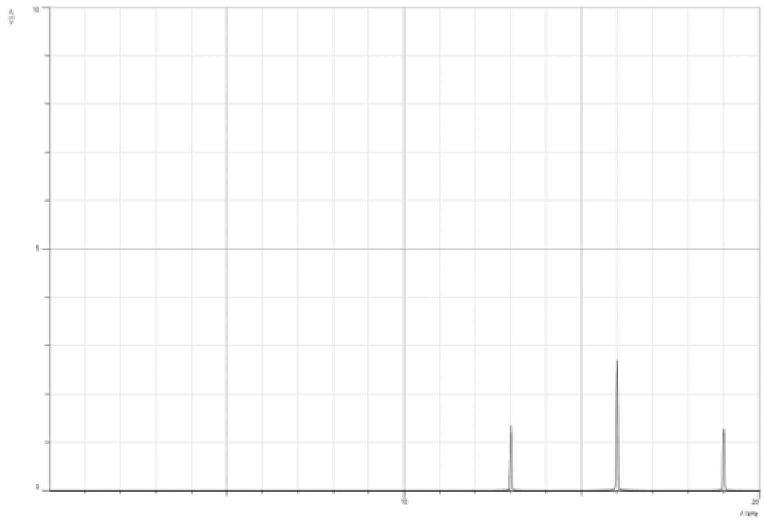

Figure 15: vss=4v, fm = 3kHz - frequency domain

Consider Figure 15, it shows the S(f) which consists of the two sidebands (upper and lower) the upper with 19 kHz, the lower sideband is 13 kHz and the carrier with fc = 16 kHz and that is a true result since the spectrum of the modulated signal after applying the Fourier Transform on the modulated signal should be:

$$S(f) = \delta(f - 16000) + \delta(f + 16000) + \delta(f - 19000) + \delta(f + 19000) \\ + 0.25\delta(f - 13000) + 0.25\delta(f + 13000)$$

So the spectrum of the modulated signal is represented as 3 impulses on the positive side, one on 16kHz which is the carrier, one on 13kHz which is the lower side band, and one on 19kHz which is the upper sideband, so the Cassy Lab software result is true. So, the change of the frequency affects the upper and lower sidebands. The band width is 19kHz – 13kHz = 6kHz which is also true since B.W = 2Fm = 2×3 = 6kHz. Where B.W is the transmission bandwidth, and W is the message signal bandwidth. So, the change of the frequency also affects the B.W of the modulated signal, when we raise the frequency of the message signal to 3 kHz the bandwidth of the modulated raised to 2 kHz. So according to the previous results, changing the frequency of the message signal in Normal AM leads to shifts in the sidebands and changes in the bandwidth of the modulated signal.

To find the power efficiency:

$$\eta = \frac{\mu^2}{2+\mu^2} = \frac{1}{2+1} = \frac{1}{3} = 0.33 = 33\%$$

1.5. The effect of changing the amplitude

a. fm = 2kHz, Change Vss to 2V

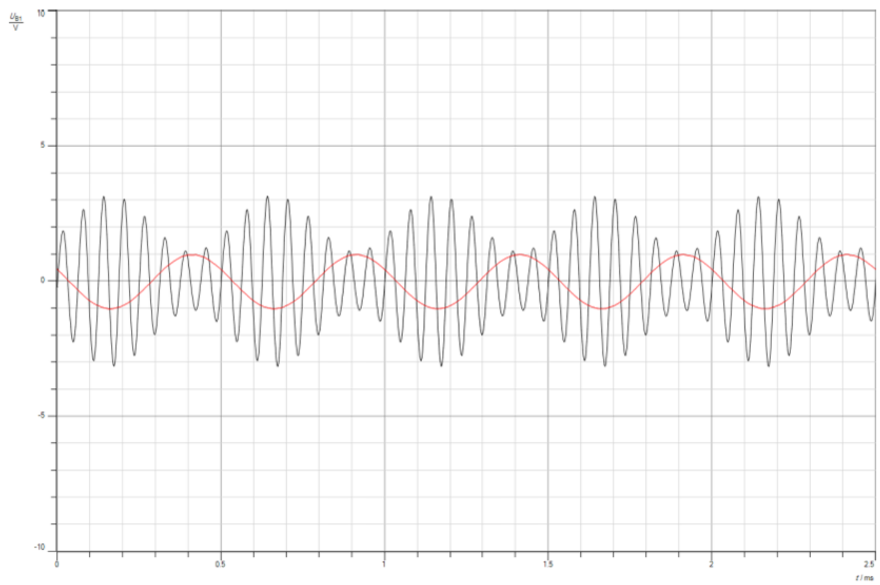

Figure 16: fm = 2kHz, Vss =2V – time domain

Consider Figure 16, the amplitude of the signal in the figure is 1Volt, and that is true since:

$$v_{ss} = 2v_m$$

Where Vss is the peek-to-peek voltage and Vm is the message voltage.

In our case Vss = 2 volt

$$2volt = 2v_m$$

$$v_m = 1\ volt$$

The modulation index has changed:

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

According to the shape in the figure Amax = 3 and Amin = 1

$$\mu = \frac{3 - 1}{3 + 1} = 0.5$$

M<1 (Under modulation) , So the change in the amplitude of the message signal affects the modulation index and also the ka:

$$k_a = \frac{\mu}{Am}$$

To find the modulator sensitivity Ka

$$\text{Ka} = \mu \times Am = 0.5 \times 1volt = 0.5\, volt^{-1}$$

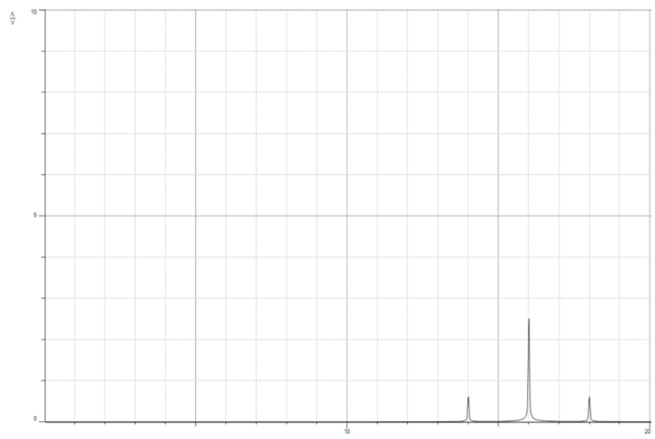

Figure 17: fm = 2kHz, Vss =2V – frequency domain

Consider Figure 17, it shows the S(f) which consists of the two sidebands (upper and lower) the upper with 18 kHz, the lower sideband is 14 kHz and the carrier with fc = 16 kHz The spectrum of the modulated signal after applying the Fourier Transform on the modulated signal should be:

$$S(f) = \delta(f - 16000) + \delta(f + 16000) + 0.25\delta(f - 18000) + 0.25\delta(f + 18000) + 0.25\delta(f - 14000) + 0.25\delta(f + 14000)$$

So the spectrum of the modulated signal is represented as 3 impulses on the positive side, one on 16kHz which is the carrier, one on 14kHz which is the lower side band, and one on 18kHz which is the upper sideband, so the Cassy Lab software result is true. The band width is 18kHz – 14kHz = 4kHz which is also true since B.W = 2Fm = 2×2 = 4kHz. No change in the frequencies. But the amplitude of the sidebands changed, so when we reduced the Vss the amplitude of the sidebands reduced.

To find the power efficiency :

$$\eta = \frac{\mu^2}{2+\mu^2} = \frac{0.25}{2+0.25} = \frac{0.25}{2.25} = 0.11 = 11\%$$

b. fm = 2kHz, Change Vss to 6V

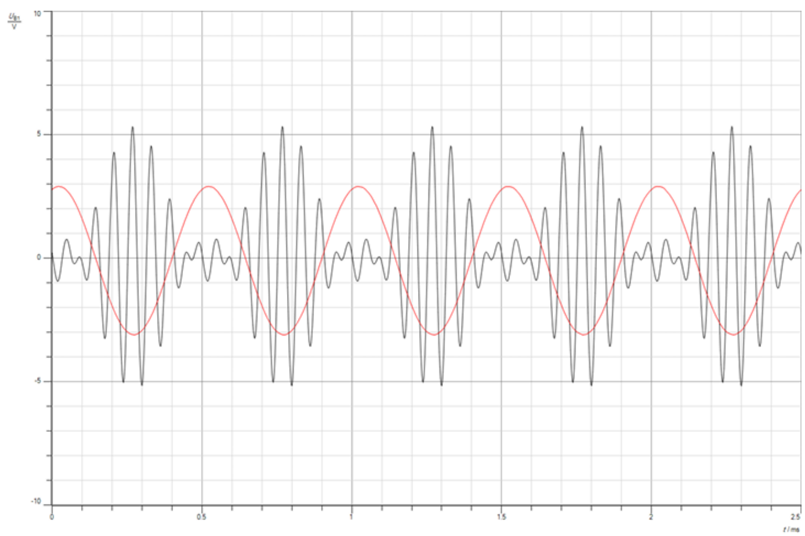

Figure 18: fm = 2kHz, Vss =6V – time domain

Consider Figure 18, the amplitude of the signal in the figure is 1Volt, and that is true since:

$$v_{ss} = 6v_m$$

Where Vss is the peek-to-peek voltage and Vm is the message voltage.

In our case Vss = 6 volt.

$$6volt = 2v_m$$

$$v_m = 3\ volt$$

The modulation index has changed:

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

According to the shape in the figure Amax = 5 and Amin = -1

$$\mu = \frac{5+1}{5-1} = 1.5$$

M> 1 (Over modulation), So the change in the amplitude of the message signal affects the modulation index and also the ka:

$$k_a = \frac{\mu}{Am}$$

To find the modulator sensitivity Ka:

$$\text{Ka} = \frac{\mu}{Am} = \frac{1.5}{3} = 0.5\ volt^{-1}$$

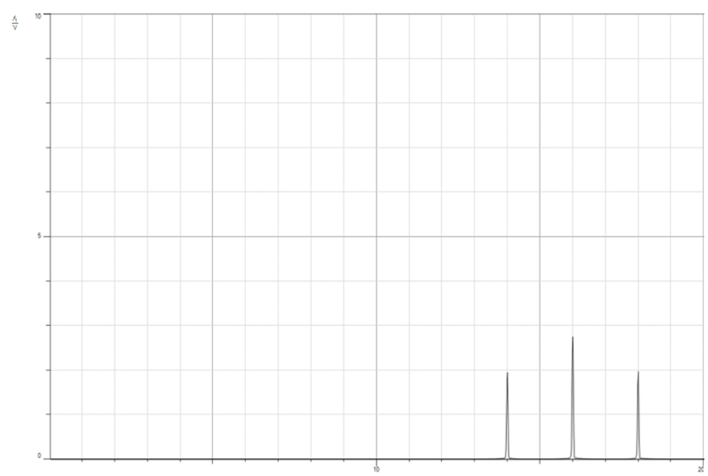

Figure 19: fm = 2kHz, Vss =6V – frequency domain

$$S(f) = \delta(f-16000) + \delta(f+16000) + 0.75\delta(f-18000) + 0.75\delta(f+18000) + 0.75\delta(f-14000) + 0.75\delta(f+14000)$$

So the spectrum of the modulated signal is represented as 3 impulses on the positive side, one on 16kHz which is the carrier, one on 14kHz which is the lower side band, and one on 18kHz which is the upper sideband, so the Cassy Lab software result is true. The band width is 18kHz – 14kHz = 4kHz which is also true since B.W = 2Fm = 2×2 = 4kHz. No change in the frequencies. But the amplitude of the sidebands changed, so when we raised the Vss to 6 the amplitude of the sidebands raised.

To find the power efficiency :

$$\eta = \frac{\mu^2}{2+\mu^2} = \frac{2.25}{2+2.25} = \frac{2.25}{4.25} = 0.53 = 53\%$$

So changing the Vss (which leads to a change in the amplitude of the signal), changes the modulation index and the amplitude of sidebands, the modulation index is directly proportional to it so that's why it changes ($\mu = ka \times Am$). Also changing the amplitude of the message signal affects the amplitudes of the upper and lower sidebands. When Vm is increased the amplitudes of the sidebands tend to be larger, and when Vm is decreased the amplitudes of the sidebands tend to be smaller.

1.6. Low pass filter phase shift effect

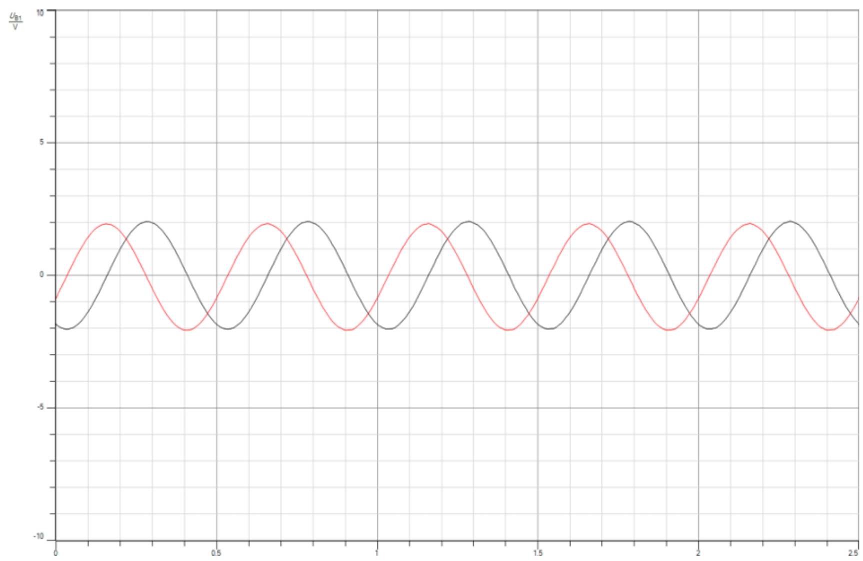

Figure 20: message signal before and after the filter-time domain

Consider Figure 20, it demonstrates that the message signal remains unchanged before and after passing through the LPF (because fm is lower than the cut-off frequency of the LPF), but there is a phase shift (90 degrees) caused by the LPF (due to the imaginary j due to the LPF's capacitor element).

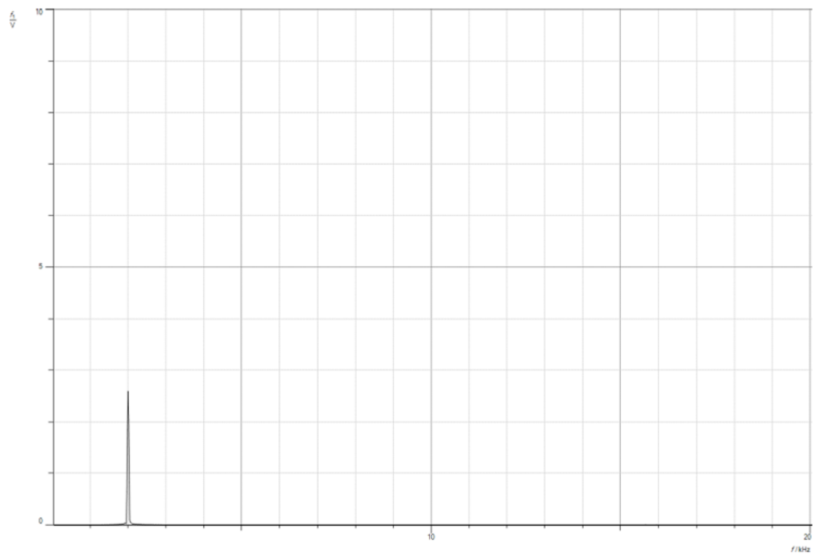

Figure 21: message signal after the LPF in the frequency domain

Consider Figure 21 which shows the message signal in the frequency domain, it remains the same as the message signal before the LPF and that is because fm is lower than the cut-off frequency of the LPF, so it will pass without any attenuation.

Change the message frequency to 7kHz :

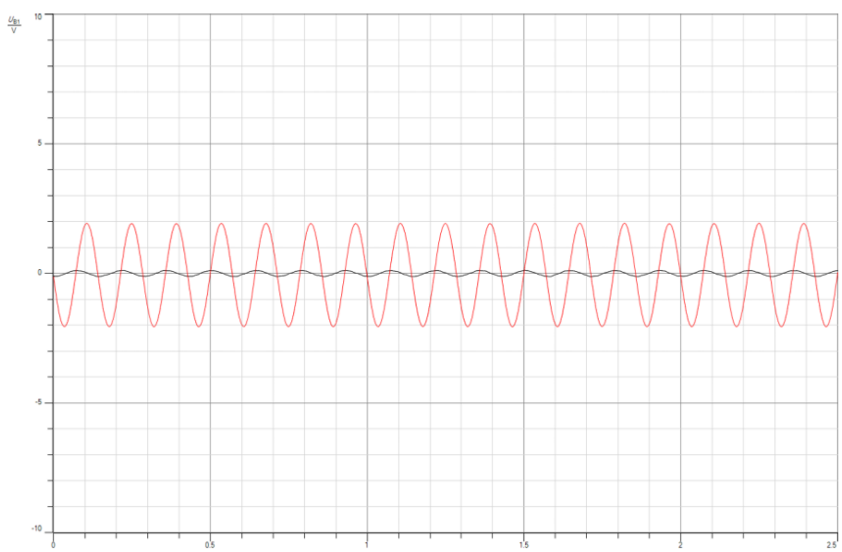

Figure 22: message signal before and after the filter-time domain-fm = 7khz

Consider Figure 22, which demonstrates that the message signal almost disappears after the filter (because fm is larger than the cut-off frequency of the LPF).

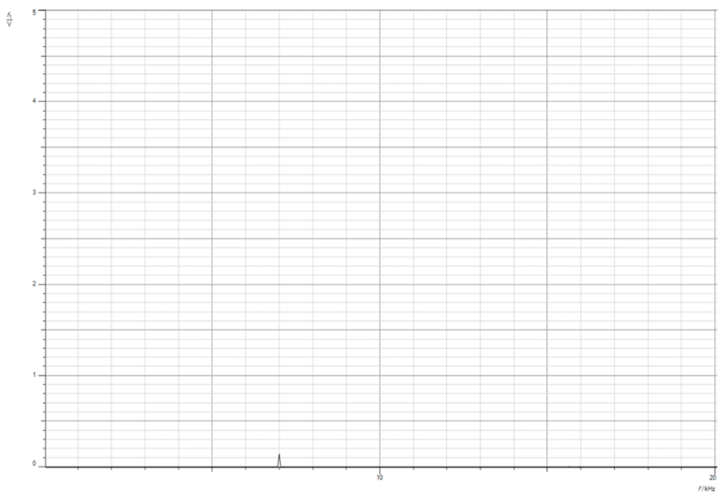

Figure 23: message signal before and after the filter-Frequency domain-fm = 7khz

Consider Figure 23 which shows the message signal after the LPF, as we can see the amplitude decreases, that is because the frequency of the message signal is higher than the cutoff frequency of the LPF.

So, When the message signal frequency exceeds the cutoff frequency of the filter, the signal m(t) almost disappear, and the amplitude of the message signal decreases. When the message signal frequency is smaller than the cutoff frequency of the filter, then no change, only the 90-degree shift.

2. Normal Amplitude Demodulation

2.1.Coherent Demodulation

We have connected the connection in Figure 24 below. In the coherent modulation, we use a carrier that has the same frequency and phase as the original carrier used in the modulation, with no phase shift, so here we set the phase controller to the left (Minimum value = 0), this carrier will be multiplied by the modulated signal, so we connect them to the multiplier block, then the output of the multiplication will be pass to the LPF, and the output of the LPF is the demodulated signal, so we connect it to channel UB1 and we connect the message signal on UA1 channel on the Cassy sensor to see the results on the Cassy Lab software.

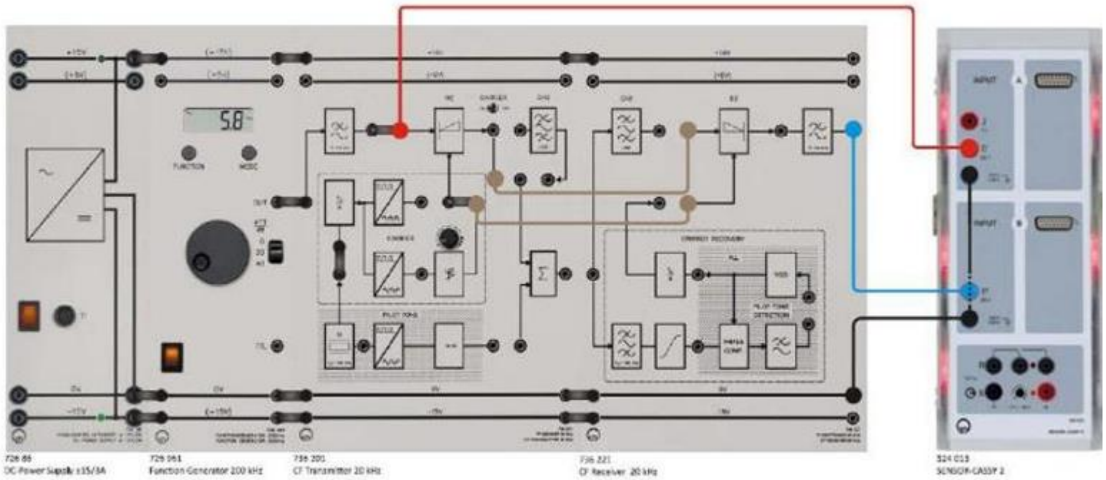

Figure 24: Coherent Demodulated Signal - Toolkit connections

Demodulated Signal and Original message Signal Before the output filter

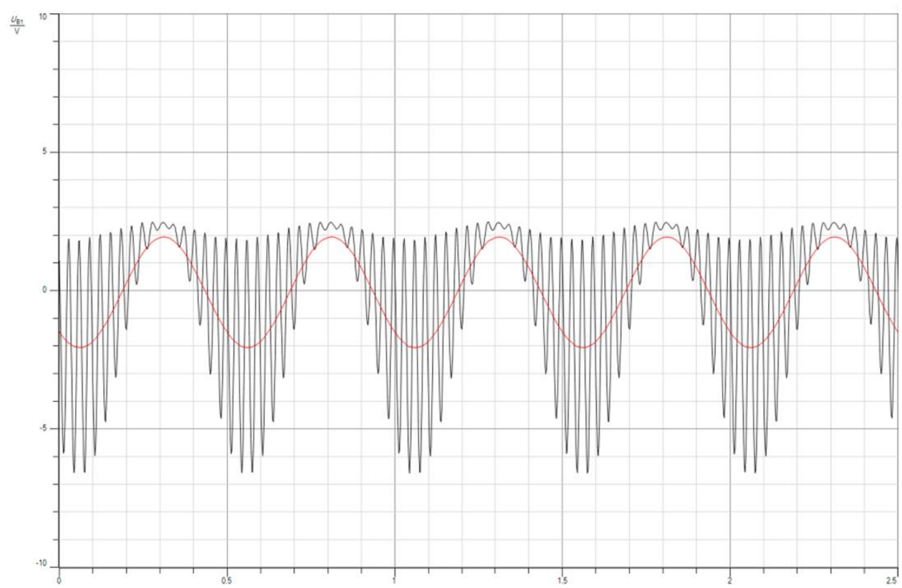

Figure 25: Coherent Demodulation - Before Filter – time domain

As we can see in Figure 25, the demodulated signal (which is in black) has a high-frequency noise and unwanted frequencies.

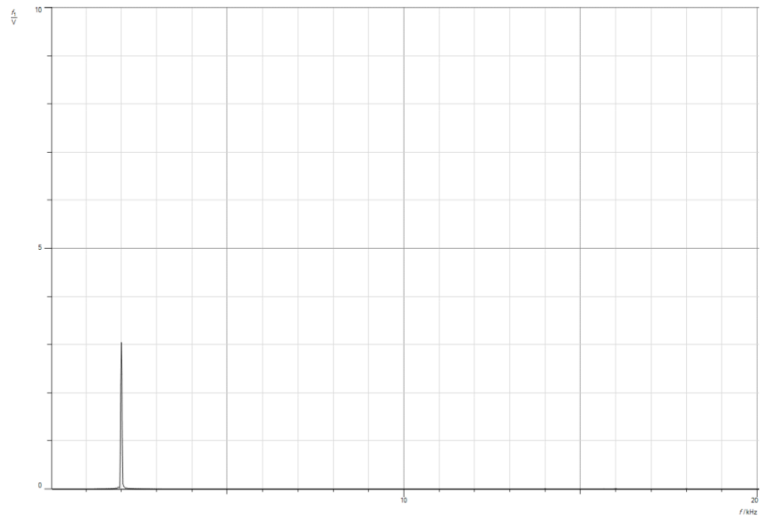

Figure 26: Coherent Demodulation –demodulated signal Before Filter – frequency domain

After filter

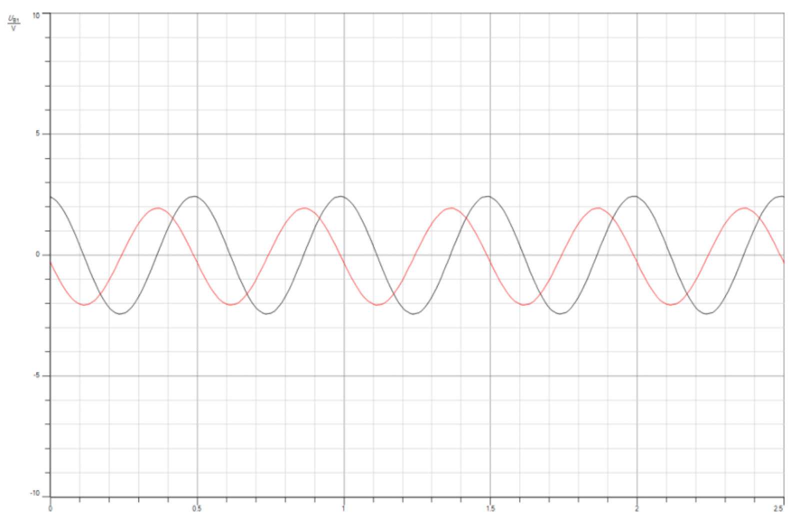

Figure 27: Coherent Demodulation - After Filter – time domain

Consider Figure 27, it demonstrates that there is a phase shift (90 degrees) caused by the LPF (due to the imaginary j due to the LPF's capacitor element), and the high-frequency noise and unwanted frequencies that we have seen in Figure 28 has gone due to the filter.

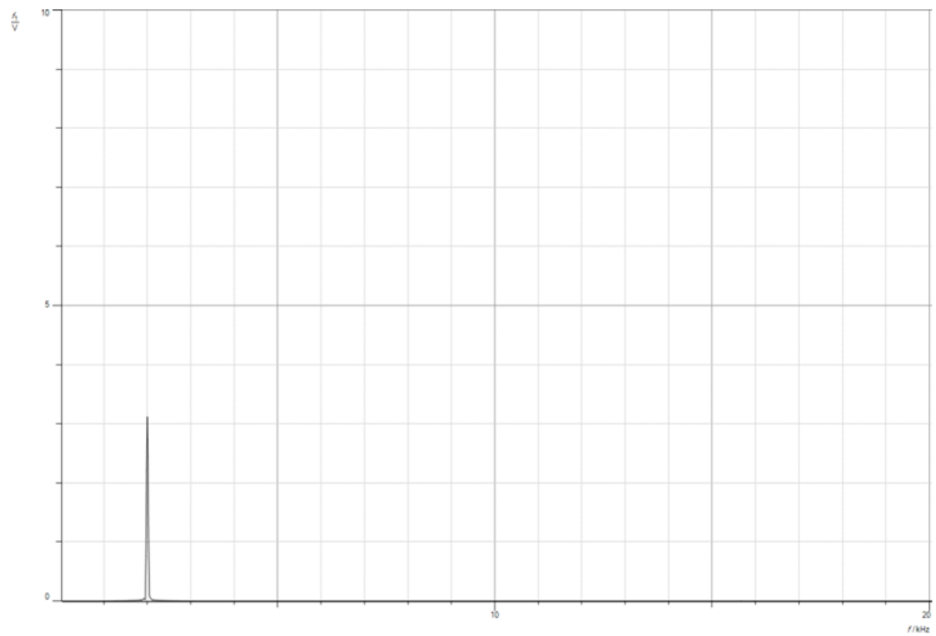

Figure 28: Coherent Demodulation - demodulated signal After Filter – frequency domain

So, the receiver output filter is necessary to attenuate the unwanted frequencies caused by the multiplication of the carrier and the modulated signal and retain only the original message signal.

$$s(t) = 2\cos(2\pi(16000)t) + \cos(2\pi(18000)t) + \cos(2\pi(14000)t)$$

$$c(t) = 2\cos(2\pi(16000)t)$$

$$\mathrm{v(t)} = \text{ Modulated signal} \times \text{Carrier signal}$$

$$v(t) = (s(t) = 2\cos(2\pi(16000)t) + \cos(2\pi(18000)t) + \cos(2\pi(14000)t))\, 2\cos(2\pi(16000)t)$$

$$\mathrm{v(t)} = (2(\cos(2\pi(32000)t) + \cos(2\pi(34000)t) + \cos(2\pi(2000)t) + \cos(2\pi(30000)t) + \cos(2\pi(2000)t))$$

The LPF will pass only frequencies that are not larger than 2000, so the output of the LPF will be

$$\cos(2\pi(2000)t) + \cos(2\pi(2000)t) = 2\cos(2\pi(2000)t)$$

Which is the same as the original message signal.

2.2. noncoherent Demodulation

Non-Coherent It is similar to coherent demodulation here, we make a phase shift on the carrier, so here we set the phase controller to 90 degrees, so we keep varying the value of the phase shift until the demodulated signal disappears (When the demodulated signal disappears that means that the phase shift = 90) so at that point when the phase difference between the two carriers is 90 degree the carrier will be canceled and that ensures getting back the message signal effectively.

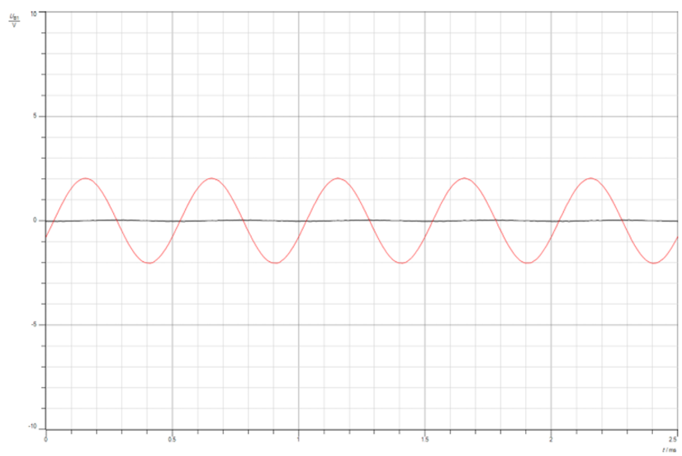

Figure 29: Non-Coherent-demodulated signal and message signal -time domain

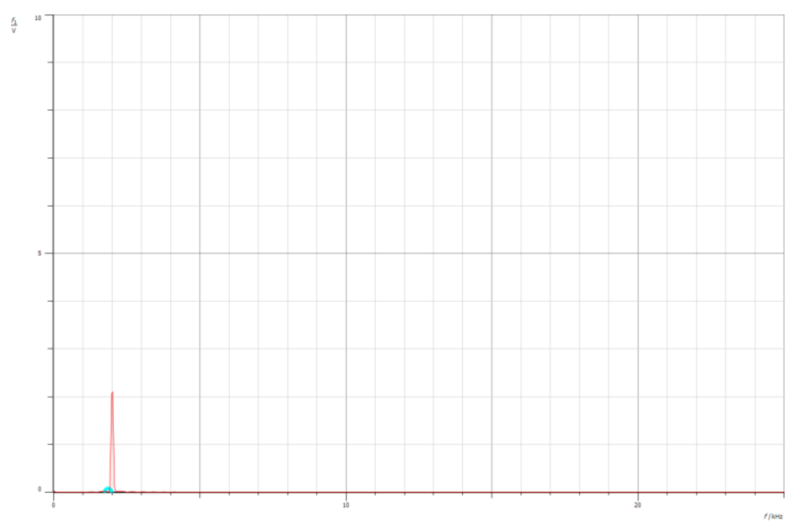

Figure 30: Non-Coherent-demodulated signal and message signal -frequency domain

Conclusion

In conclusion, there are three modulation types: under modulation, normal modulation, and over modulation depending on the modulation index value. The modulation process is critical to transmit the signal into any environment and on the other hand, the receiver uses demodulation methods to recover the signal. According to the transmitter, the value of the signal frequency is very important because it determines the signal bandwidth, and the frequency determines the value of the signal modulation index which determines the modulation type. In this experiment there are two demodulation methods “coherent and non-coherent” and the prelab contains an extra one which is the envelop detector. The practical results same as the theoretical one, and the best case of the modulation signal is when it's equal to 1 “Normal Modulation” and the worst case is when it's greater than 1 “Over Modulation”.

References

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