Prelab 6 : 100%
LabRep 6 : 94%

Jacobs University Bremen

Signals & Systems
Fall Semester 2020

Lab Experiment: AM Modulation

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Place of execution : Teaching Lab EE
Date of execution : 11th November, 2020

Objectives:

The goal of this experiment of the Signals and Systems Lab is to study different analog modulation techniques. In the first part of the experiment amplitude modulation will be investigated. We will examine the properties of double-sideband (DSB) modulation, double-sideband suppressed carrier (DSB-SC) modulation, and single-sideband amplitude (SSB) modulation and their frequency spectra. The techniques used for demodulation will be explained. Practically, the oscilloscope will be used to demonstrate the impact of the amplitude modulation parameters on the modulated signal in time and frequency domain. Furthermore, you will build a complete amplitude modulation-based system using the function generator as a modulator and the envelope detector circuit as a demodulator. In the second part of the experiment frequency modulation will be investigated. The influence of frequency modulation parameters on the bandwidth will be explained. Practically, the oscilloscope will be used as a spectrum analyzer to demonstrate the impact of the frequency modulation parameters on the frequency domain. Furthermore, you will build a simple demodulation circuit consisting of a slope detector.

Theory:

The theory used to of communications systems and their amplitude modulation. One of the final steps before the transmission of the signal is modulation and one of the first steps on receiving the signal is demodulation. Modulation is the process of embedding an information-bearing signal into a second carrier signal while extracting the information bearing signal is known as the demodulation process. One large class of modulation methods relies on the concept of amplitude modulation (AM) in which the signal we wish to transmit is used to modulate the amplitude of another signal. A very common form of amplitude modulation is sinusoidal amplitude modulation in which the information signal is used to vary the amplitude of a sinusoidal signal. Another important form of AM system involves the modulation of the amplitude of a pulsed signal, which is called pulse amplitude modulation (PAM). A wide variety of modulation methods are used in practice.

7.4 Prelab AM Modulation

7.4.1 Problem 1: Single frequency Amplitude Modulation

1. Derive an expression describing the modulation index m as a function of the modulation envelope, (use Amin and Amax!).

The modulation index is given by

$$m = \frac{\text{Amplitude of modulating signal}}{\text{Amplitude of carrier signal}}$$

$$m = \frac{V_m}{V_c}$$

$$\text{Where } V_m = \frac{V_{pp}}{2} = \frac{V_{max} - V_{min}}{2} \text{ And } V_c = \frac{V_{max} + V_{min}}{2}$$

$$V_{\text{max}} = \text{A}_{\text{max}} \text{ and } V_{\text{min}} = \text{A}_{\text{mi}}$$

$$m = \frac{\text{A}_\text{m}}{A_C} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

2. Derive an expression describing the ratio of the total sideband power to the total power rP = Ps/Ptot in the modulated wave delivered to a load resistor. Express the ratio in terms of the modulation index.

Ratio of total sideband power:

$$r_P = \frac{P_s}{P_{tot}} \text{ and } m = k \times A_m$$

Now let us assume our signal modulated/carrier signals are sinusoidal:

$$y(t) = A_c[1 + kA_m \cos(2\pi f_m t)] \cos(2\pi f_C t)$$
$$= A_c \cos(2\pi f_C t) + \frac{A_C m}{2} \cos(2\pi(f_m + f_C)t)$$

Using trigonometric identities, we can expand the above:

$$y(t) = A_c \cos(2\pi f_C t) + \frac{A_C m}{2} \cos(2\pi(f_C + f_m)t) + \frac{A_C m}{2} \cos(2\pi(f_C - f_m)t)$$

We know that $P = \frac{V^2}{R}$ so, the sideband power would be $= \frac{1}{R}\left(\frac{A_C^2 m^2}{4} \times \frac{1}{2} + \frac{A_C^2 m^2}{4} \times \frac{1}{2}\right) =$

$\frac{2\times(mA_C)^2}{4R}$ and the carrier power$= \frac{1}{R}\left(\frac{A_C^2}{2}\right) = \frac{A_C^2}{2R} \rightarrow$ the total power $= \frac{1}{R}\left(\frac{2\times(mA_C)^2}{4} + \frac{A_C^2}{2}\right)$

$$r_p = \frac{P_s}{P_{tot}} = \frac{\frac{2(mA_C)^2}{4R}}{\left(\frac{2(mA_C)^2}{4R} + \frac{(A_C)^2}{2R}\right)} = \frac{2(mA_C)^2}{2(mA_C)^2 + 2A_C^2} = 1 - \frac{2}{m^2+2} = \frac{m^2}{2+m^2}$$

3. Calculate the ratio rP assuming a modulation index of 100%.

When modulation index =100%, this means m= 1 since modulation index is a ratio.

Putting m=1 in equation found above:

$$r_p = \frac{m^2}{2+m^2} = \frac{1^2}{2+1^2} = \frac{1}{3}$$

4. A Carrier VC(t) = 5 cos (20000πt) is AM modulated by a signal Vm(t) = 2 + cos (2000πt) Calculate the ratio rP . How would you change the input signals to maximize the sideband to total power ratio?

$$V_C = 5\cos(2000\pi t) \text{ and } V_m = 2 + \cos(2000\pi t)$$

Similarly to part 2 of the prelab, we can use the same equation to express these signals with a little modification:

$$y(t) = (A_c + v_{off})\cos(2\pi f_C t) + \frac{A_C m}{2}\cos(2\pi(f_m + f_C)t) + \frac{A_C m}{2}\cos(2\pi(f_C - f_m)t)$$

The sideband power will also be the same as the carrier power of part 2, however the carrier power will be modified as $= \frac{(A_C+v_{off})^2}{R}$ and the total power$= \frac{(A_C+v_{off})^2}{R} + \frac{(mA_C)^2}{2R}$

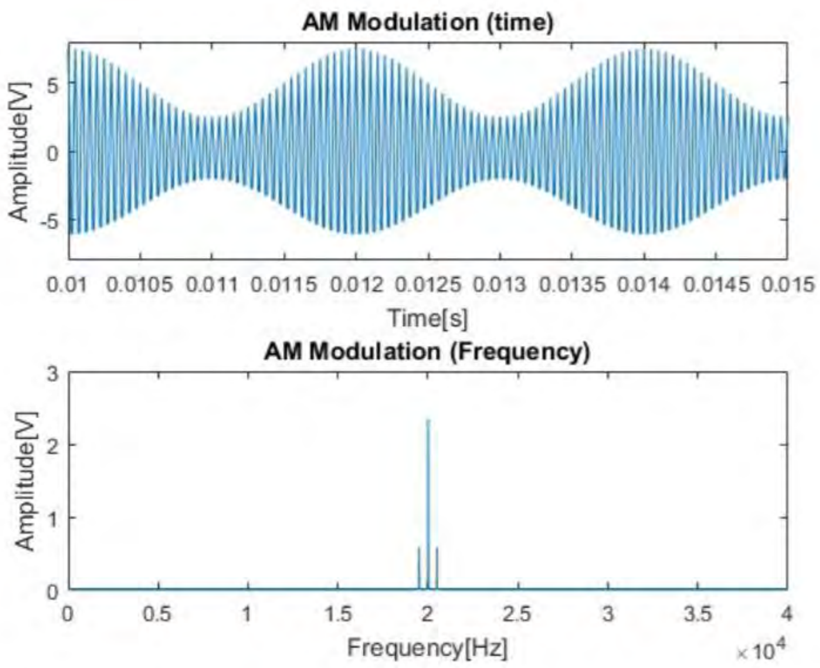
$$\rightarrow r_P = \frac{P_s}{Ptot} = \frac{\left(\frac{(A_C+v_{off})^2}{R}\right)}{\frac{(A_C+v_{off})^2}{R} + \frac{(mA_C)^2}{2R}} = \frac{2(A_C+v_{off})^2}{2(A_C+v_{off})^2 + (mA_C)^2} \rightarrow mA_C = 1, \rightarrow r_p = 1 - \frac{1}{100}$$
$$= \frac{1}{99}$$

The maximum value m can have is 1, to maximize it we can use the relation $m = k \times Am = \frac{A_m}{A_C}$ where increasing the voltage can help us to make Am and Ac equal.
Another way is using the equation above, where the m should be increase or the offset voltage should become smaller.

7.4.2 Problem 2: Amplitude Demodulation

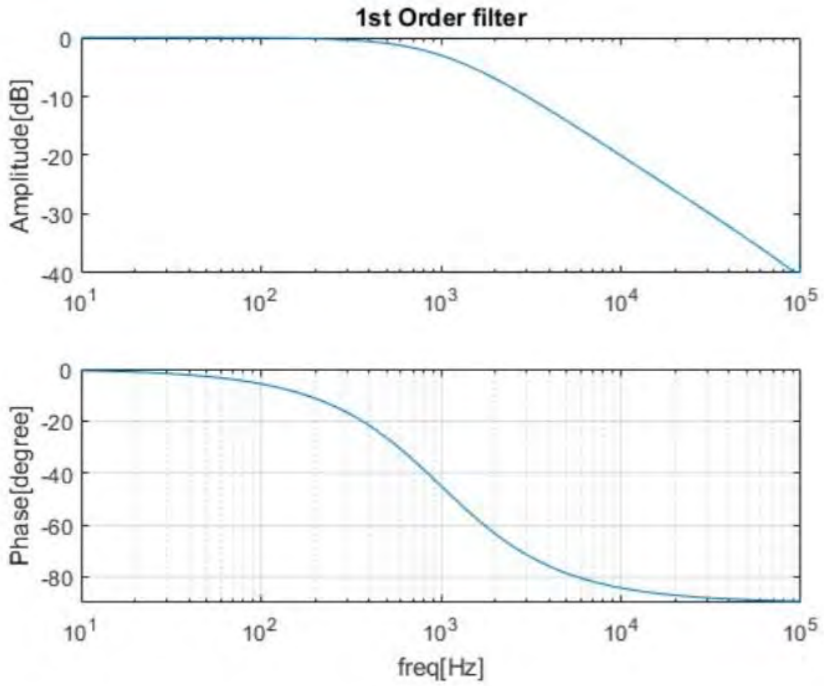
1. Plot the modulated signal in time and frequency domain.

```
 % Time Domain
clear all;
clc;
fc=20000;
fm=500;
amp= 5;
fs= fc*128;
t= 0:1/100e3:1;

vm= amp*cos(2*pi*fm*t)*0.5;
V=(amp+vm).*cos(2*pi*fc*t);
subplot(2,1,1);
plot(t,V);
xlim([0.01 0.015]);
ylim([-8 8]);
title('AM Modulation (time)');
ylabel('Amplitude[V]');
xlabel('Time[s]');

% Frequency Domain
nfft=length(V);
Vfft=fft(V)/nfft;
subplot(2,1,2);
plot(abs(Vfft));
xlim([0 4e4]);
title('AM Modulation (Frequency)');
ylabel('Amplitude[V]');
xlabel('Frequency[Hz]');
```



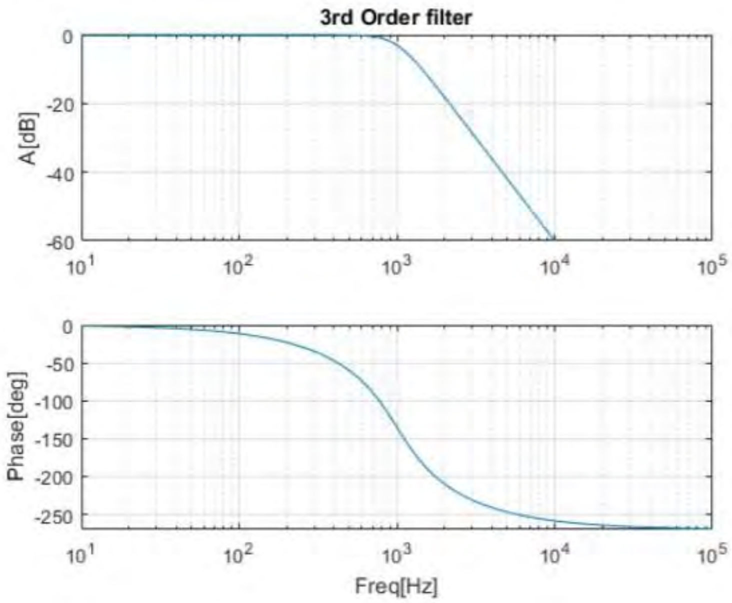
2. Design a first and a third order low pass filter (butterworth filter) to demodulate the signal. The cut-off frequencies of the filters should be 1 KHz. Plot the Bode diagram of these filters for a frequency range from 100 Hz to 100 KHz to verify the function.

```
fs=2*10^4*32;

fcut=1000;

[b,a]= butter(1,1000/(fs/2));

[f,l]=freqz(b,a,fs/2,fs);

subplot(2,1,1);

semilogx(l,20*log(abs(f))/log(10));

axis([10 100000 -40 0]);

title('1st Order filter');
ylabel('Amplitude[dB]');

subplot(2,1,2)
semilogx(l,180/pi*angle(f));
axis([10 100000 -90 0]);
grid on;
ylabel('Phase[degree]');
xlabel('freq[Hz]');
```

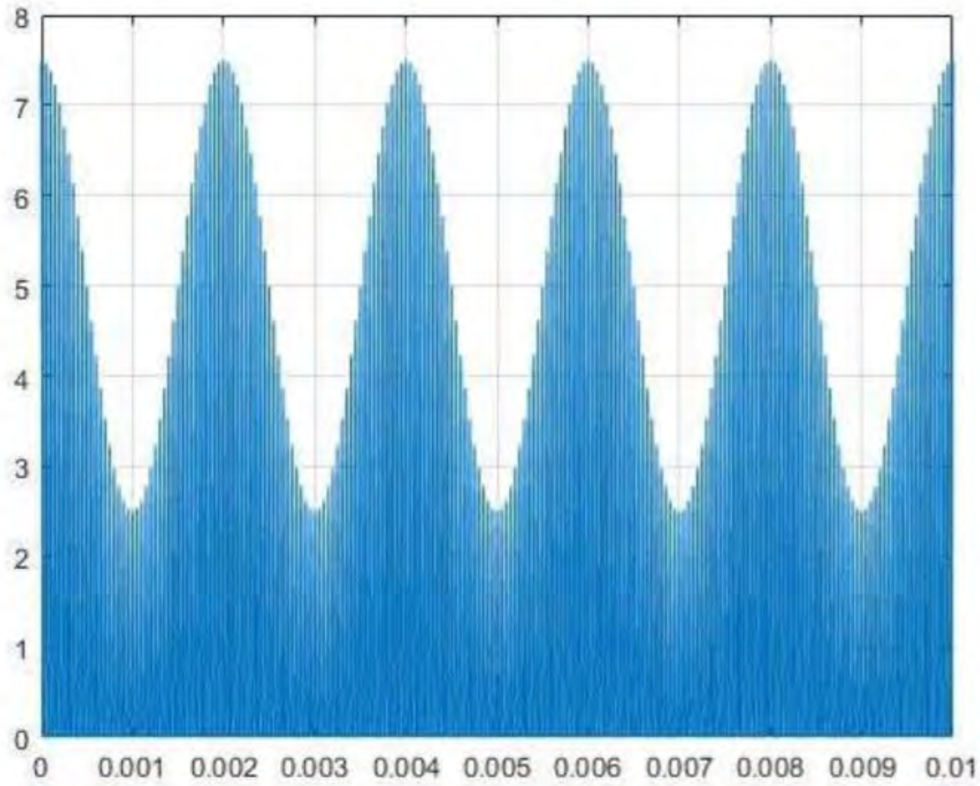


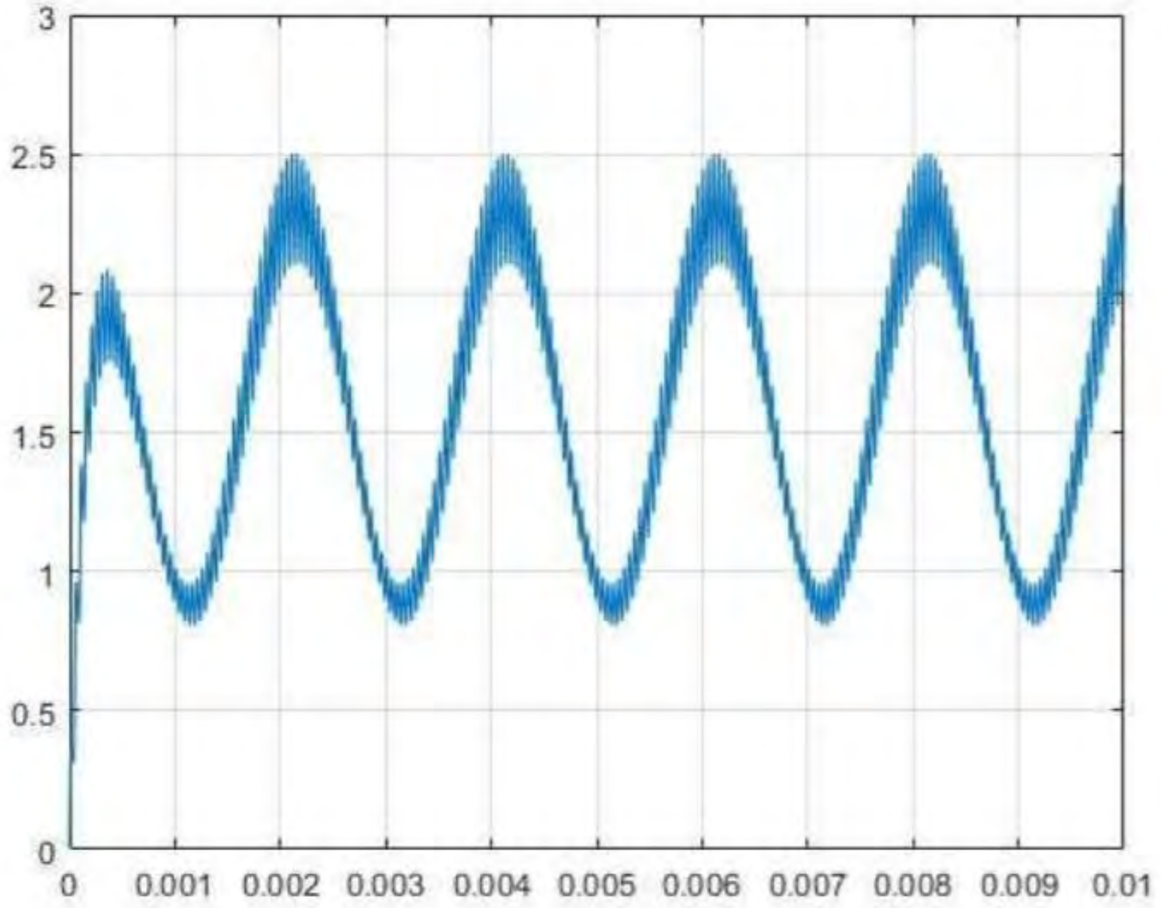
```
fs=2*10^4*32;

fcut=1000;



[am, bm]=butter(3,1000/(fs/2)); %%change order to 3
[s,e]=freqz(am,bm,fs/2,fs);
subplot(2,1,1);
semilogx(e,20*log(abs(s))/log(10));
axis([10 100000 -60 0]);
grid on;
title('3rd Order filter');
ylabel('A[dB]');

%%angle change since there is a change in gradient:
subplot(2,1,2);
th=zeros(1,length(s));
l=180/pi;
for i=1:length(s)
    if((sign(imag(s(i)))==1)&&(sign(real(s(i)))==-1));
    th(i)=l*angle(s(i))-360;
    else
        th(i)=l*angle(s(i));
    end
end

semilogx(e,th);
axis([10 100000 -270 0]);
grid on;
xlabel('Freq[Hz]');
ylabel('Phase[deg]');
```

3. Rectify the AM modulated signal and apply the 1. order low pass filter to the rectified signal. Plot the rectified and the demodulated signal.

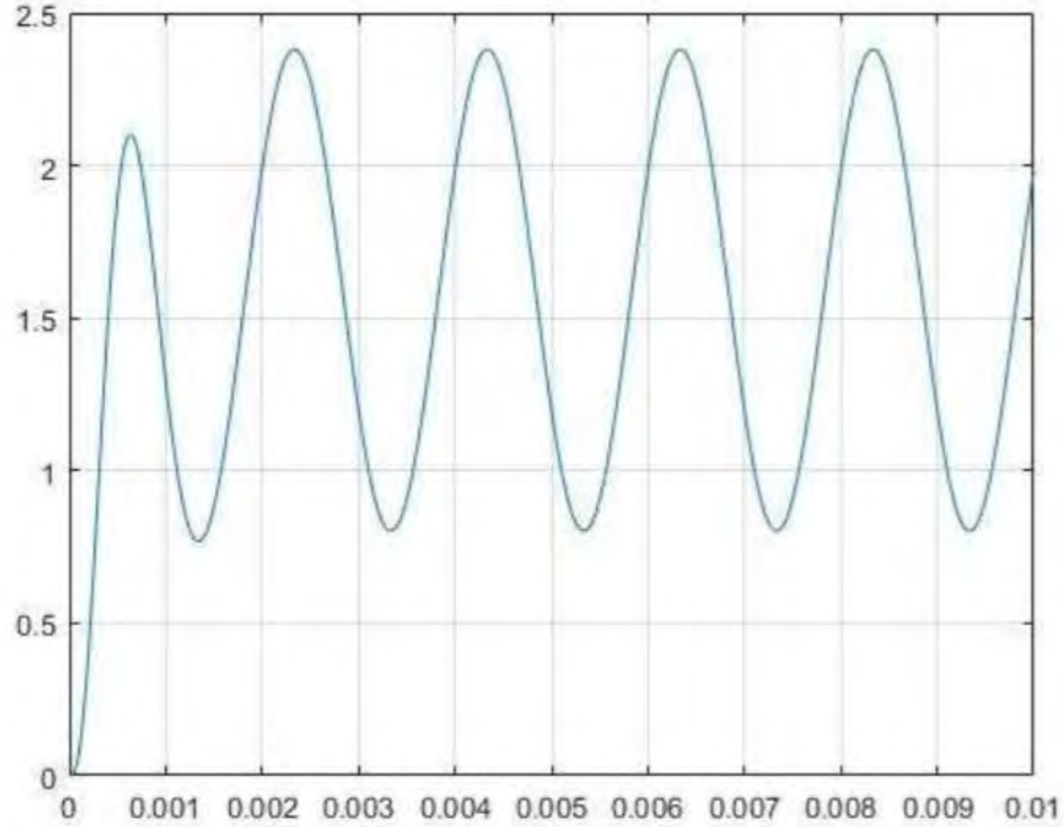


3. Rectify the AM modulated signal and apply the 1. order low pass filter to the rectified signal. Plot the rectified and the demodulated signal.




3
2.5
2
1.5
1
0.5
0
0 0.001 0.002 0.003 0.004 0.005 0.006 0.007 0.008 0.009 0.01

4. *Change the order of the filter from 1. to 3. Plot the demodulated signal.*



5. Why is it better to use a higher order filter for the demodulation of the signal?

We can conclude that it would be better to use the higher order filter during the demodulation stage, since the higher order contributions are reduced in comparison to lower order filters. We will see that the first order filter recovers the main shape of the signal, however the demodulated signal still has a significant amount of high frequency components in it which is represented by the time domain view.
The third order filter is like the original message signal since the higher frequencies have been drastically reduced or eliminated. Keeping in mind that both of our demodulated signals we obtained are scaled versions of the original signals.

6. Attach the full Matlab script to the prelab.

```
% Time Domain
clear all;
clc;
fc=20000;
fm=500;
amp= 5;
fs= fc*128;
t= 0:1/100e3:1;

vm= amp*cos(2*pi*fm*t)*0.5;
V=(amp+vm).*cos(2*pi*fc*t);
subplot(2,1,1);
plot(t,V);
```

```
xlim([0.01 0.015]);
ylim([-8 8]);
title('AM Modulation (time)');
ylabel('Amplitude[V]');
xlabel('Time[s]');

% Frequency Domain
nfft=length(V);
Vfft=fft(V)/nfft;
subplot(2,1,2);
plot(abs(Vfft));
xlim([0 4e4]);
title('AM Modulation (Frequency)');
ylabel('Amplitude[V]');
xlabel('Frequency[Hz]');


%% First and Third order filter

fs=2*10^4*32;
fcut=1000;
[b1,a1]= butter(1,1000/(fs/2));
[f,l]=freqz(b1,a1,fs/2,fs);
subplot(2,1,1);
semilogx(l,20*log(abs(f))/log(10));
axis([10 100000 -40 0]);
title('1st Order filter');
ylabel('Amplitude[dB]');
```

```
subplot(2,1,2)
semilogx(l,180/pi*angle(f));
axis([10 100000 -90 0]);
grid on;
ylabel('Phase[degree]');
xlabel('freq[Hz]');
%%
%%3rd order low pass filter Magnitude plot
fs=2*10^4*32;
fcut=1000;

[b2, a2]=butter(3,1000/(fs/2)); %%change order to 3
[f,l]=freqz(b2,a2,fs/2,fs);
subplot(2,1,1);
semilogx(l,20*log(abs(f))/log(10));
axis([10 100000 -60 0]);
grid on;
title('3rd Order filter');
ylabel('A[dB]');

%%angle change since there is a change in gradient:
subplot(2,1,2);
th=zeros(1,length(f));
l=180/pi;
for i=1:length(f)
    if((sign(imag(f(i)))==1)&&(sign(real(f(i)))==-1));
    th(i)=l*angle(f(i))-360;
    else
        th(i)=l*angle(f(i));
    end
end



semilogx(l,th);
axis([10 100000 -270 0]);
grid on;
xlabel('Freq[Hz]');
ylabel('Phase[deg]');


%% Rectification
mod_sign_rect=V.*(V>0);
figure(3);
plot(t, mod_sign_rect);
grid on;
xlim([0 0.01]);

%% Filtering the signal

dem_sign_1stOrd=filter(b1,a1,mod_sign_rect);
figure(6)
plot(t,dem_sign_1stOrd);
grid on;
%%
dem_sign_3rdOrd=filter(b2,a2,mod_sign_rect);
figure(7)
plot(t,dem_sign_3rdOrd);
grid on;
```

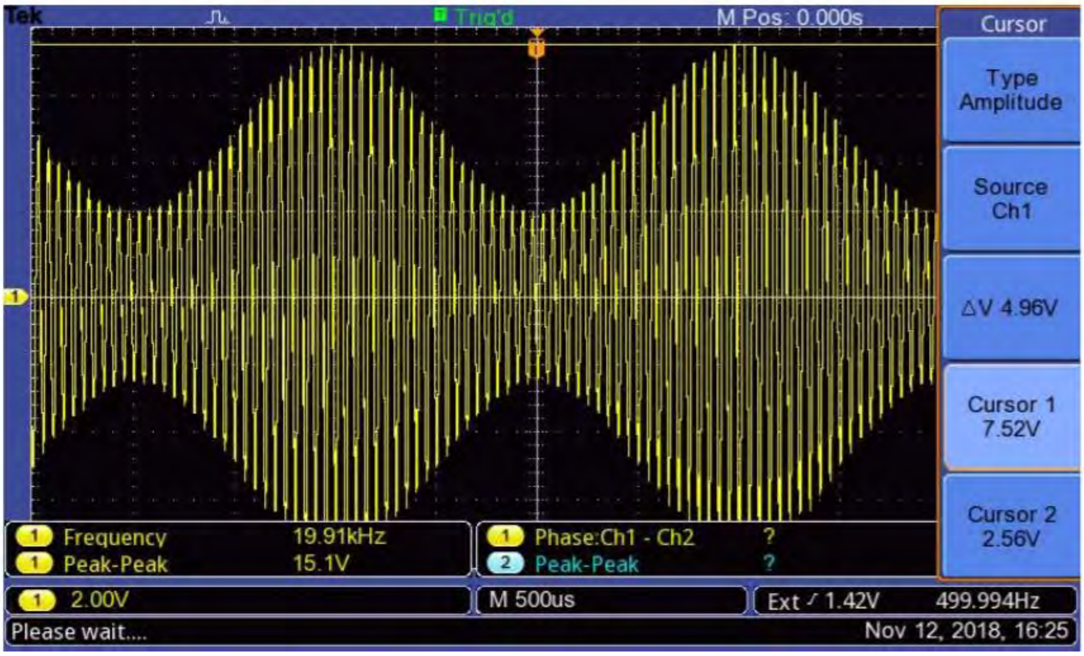
7.5 Execution AM Modulation

7.5.1 Problem 1: AM modulated Signals in Time Domain

The Oscilloscope settings used for this part were:

- Signal Shape: Sine
- Modulation: AM
- Carrier Frequency:20kHz
- Carrier Amplitude: 10Vpp
- Modulation Frequency: 500Hz
- Modulation Index: 50%

1. 50% Modulation index



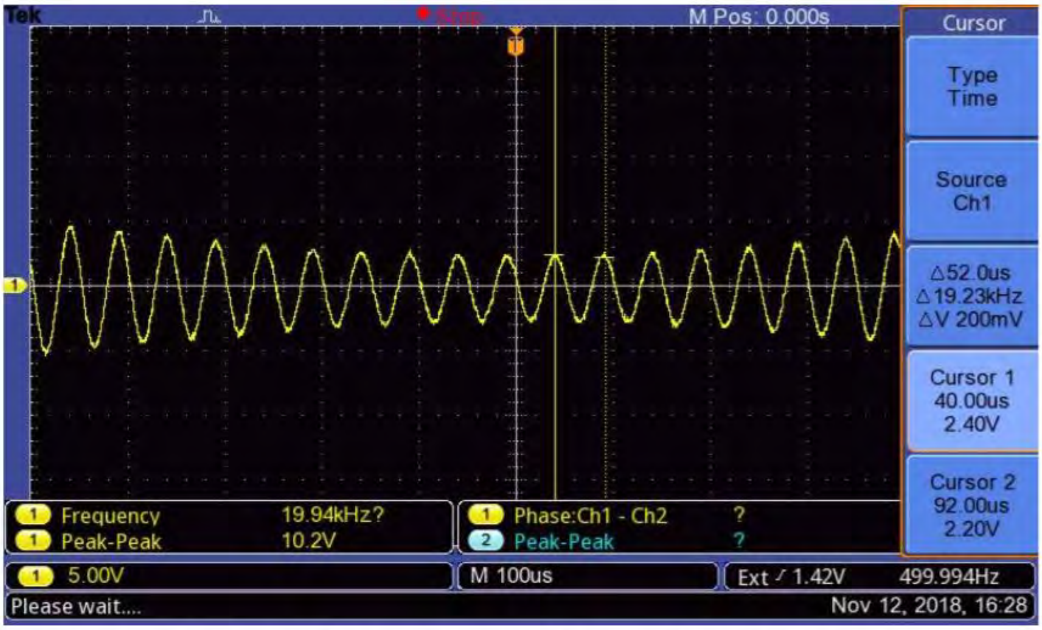
The modulation index can be calculated using the formula

$$m = \frac{\text{Amplitude}_{\text{max}}\text{-Amplitude}_{\text{min}}}{\text{Amplitude}_{\text{max}} + \text{Amplitude}_{\text{min}}}$$

We setup cursor 1 and 2 to obtain the values for amplitude and put in the equation above.

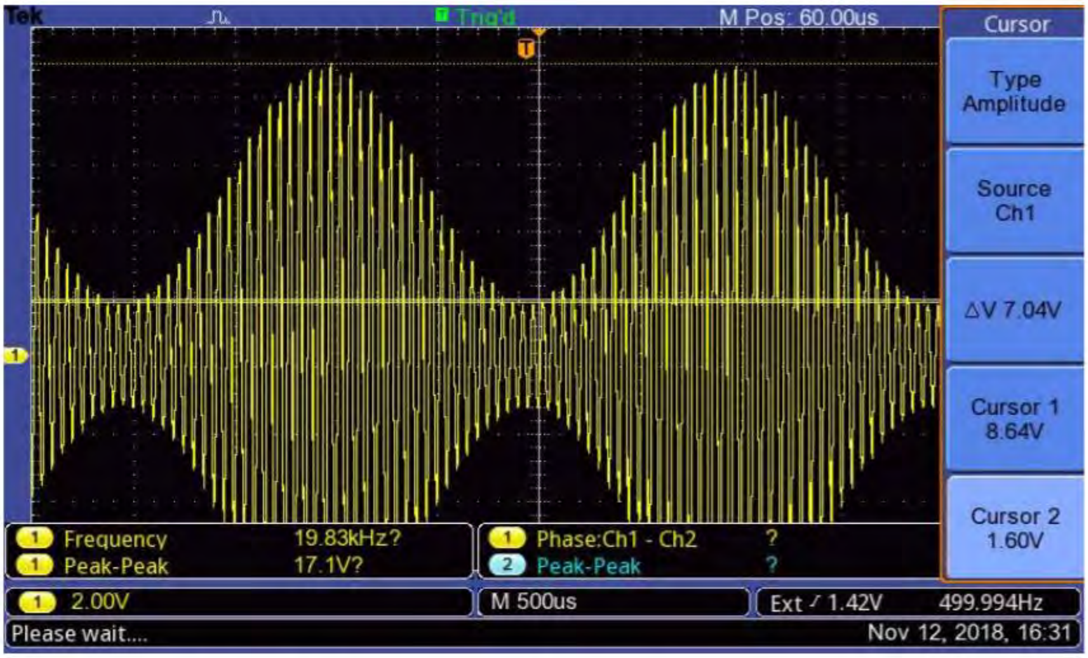
$$m = \frac{7.52\text{-}2.56}{7.52 + 2.56} \times 100 = 49.2\%$$

We can compare our modulation index that is calculated to the one that is pre-set into the generator, and we can see that these two values are very similar.



Then we used the cursors to measure the carrier frequency. i.e. approximately 20KHz(19.94KHz). And the Modulation Frequency can be seen is 500Hz.

2. Modulation Index =70%

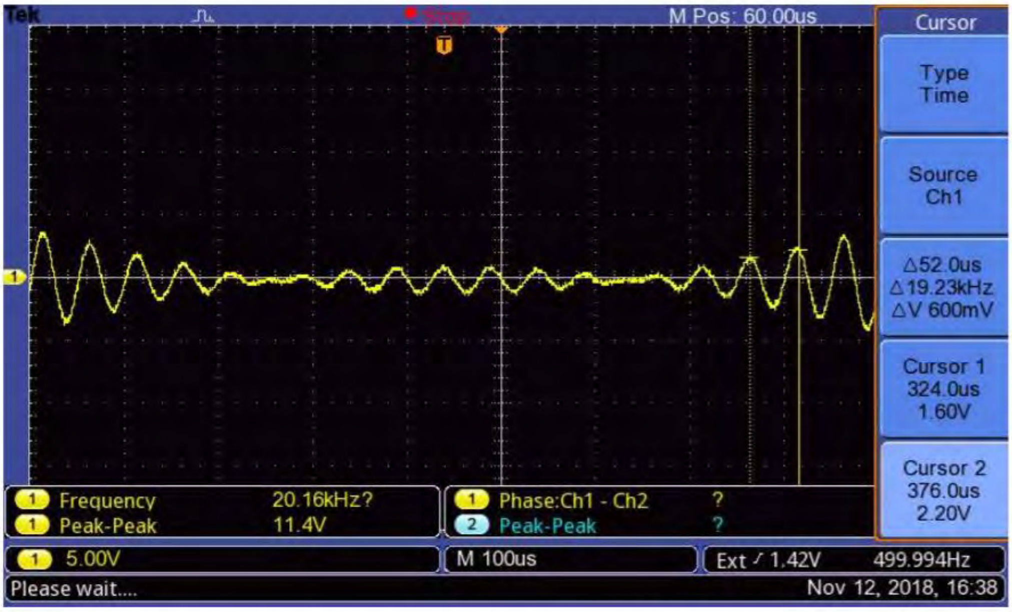


The modulation index can be calculated using the formula

$$m = \frac{\text{Amplitude}_{\text{max}}\text{-Amplitude}_{\text{min}}}{\text{Amplitude}_{\text{max}} + \text{Amplitude}_{\text{min}}}$$

We setup cursor 1 and 2 to obtain the values for amplitude and put in the equation above.

$$m = \frac{8.64\text{-}1.60}{8.64 + 1.60} \times 100 = 68.75\% \approx 70\%$$



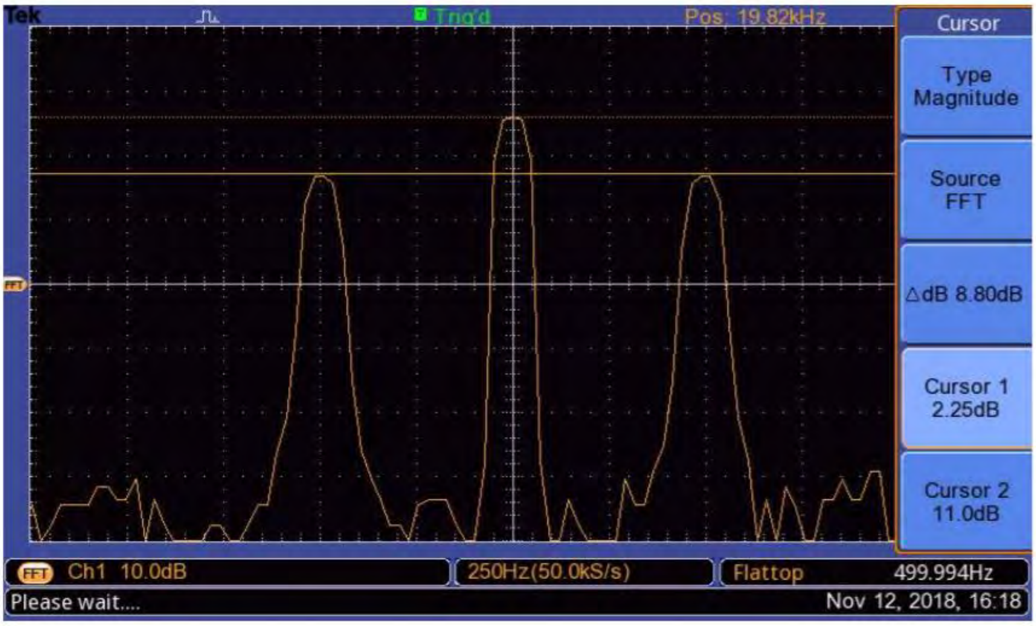
Then we used the cursors to measure the carrier frequency. i.e. approximately 20KHz(20.09KHz). And the Modulation Frequency can be seen is 500Hz.

7.5.2 Problem 2: AM Modulated Signals in Frequency Domain

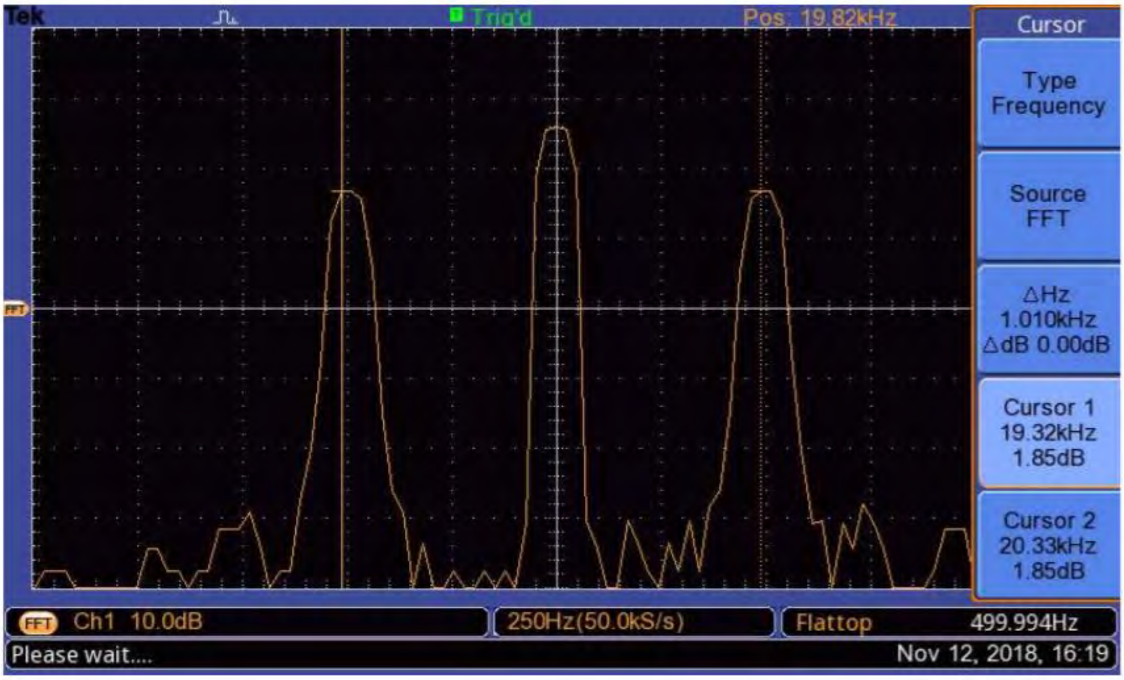
Setting modulation index to 70%.

Taking Hardcopies of FFT spectrum and using cursors to measure the magnitude and frequencies.

Amplitude:



Frequency:



tabulate the relevant values!

7.5.3 Problem 3: Demodulation of a message signal

Materials Used:

- Generator
- Oscilloscope
- BNC-to-Kleps
- 2 Resistors
- 1 amplifier
- 2 Capacitors
- 1 Inductor
- Wires
- Jumper Wires
- ELABO

Procedure:

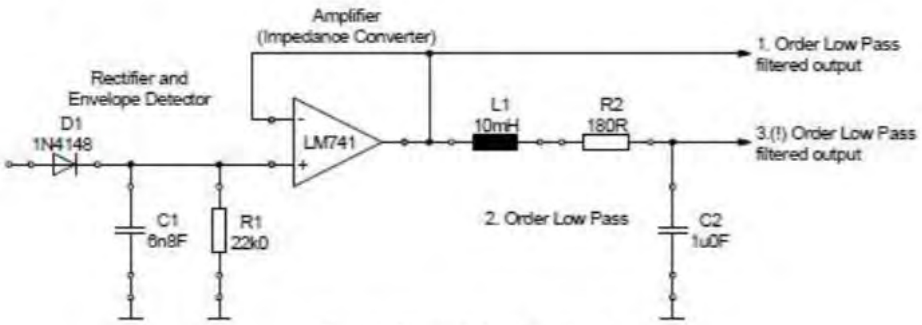
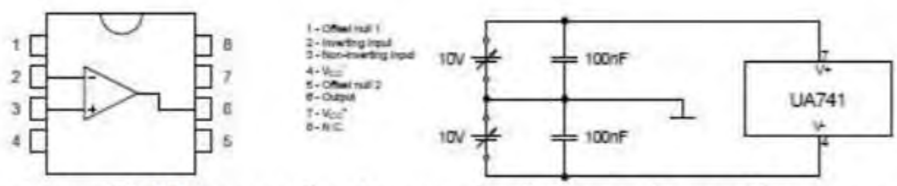


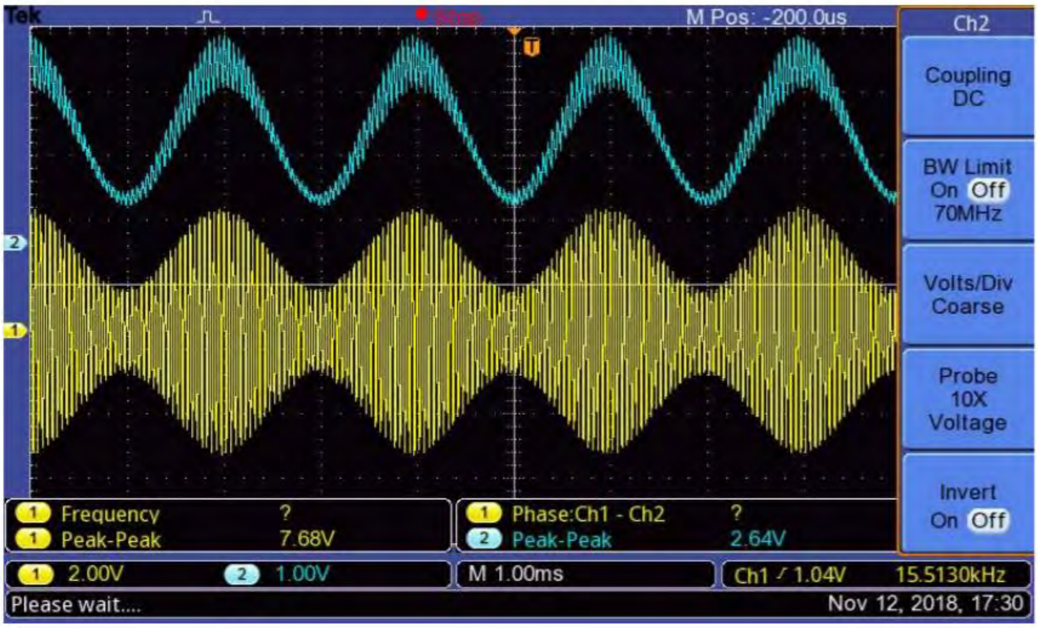
Fig. 1: Demodulation circuit

1) Start off by calibrating your channel 1 on your oscilloscope in order to get a correct signal.
2) Connect the generator using the BNC-to-Kleps cable, next set your generator to produce:
    a. *Signal Shape:* Sine
    b. *Modulation:* AM
    c. *Carrier Frequency:*20kHz
    d. *Carrier Amplitude:* 10Vpp
    e. *Modulation Frequency:* 500Hz
    f. *Modulation Index:* 50%
3) Connect your circuit as seen in the above figure.
4) The connection of the amplifier should follow the following diagram:

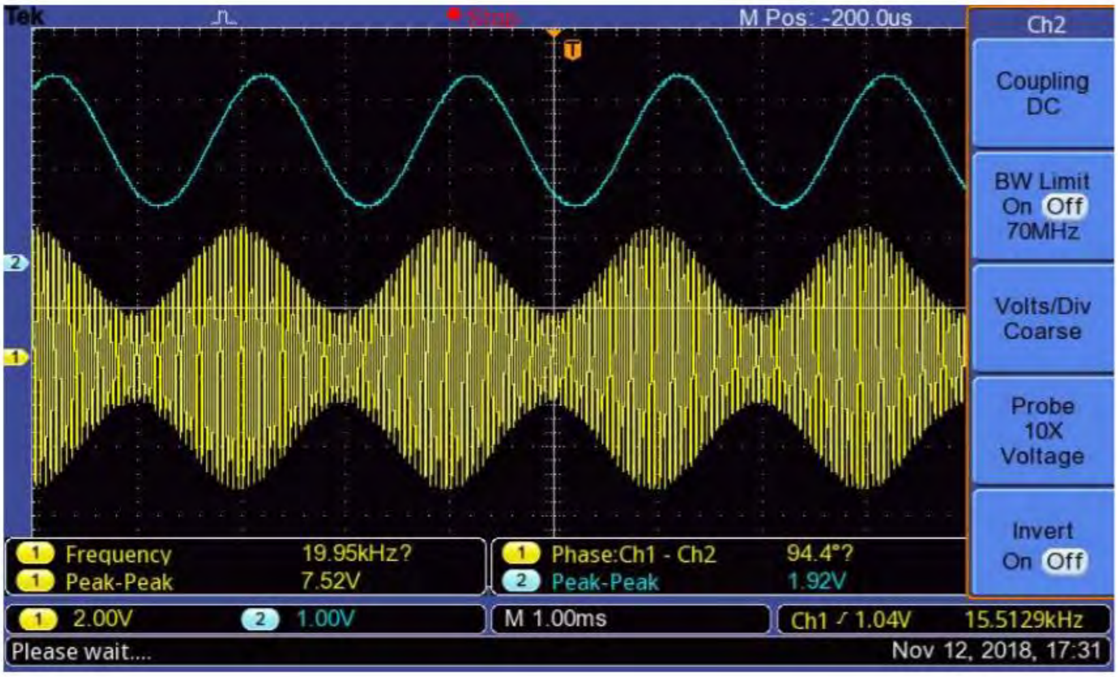


5) Connect your ELABO according to your circuit connection and image seen above. Such that the voltage is set to 10V.

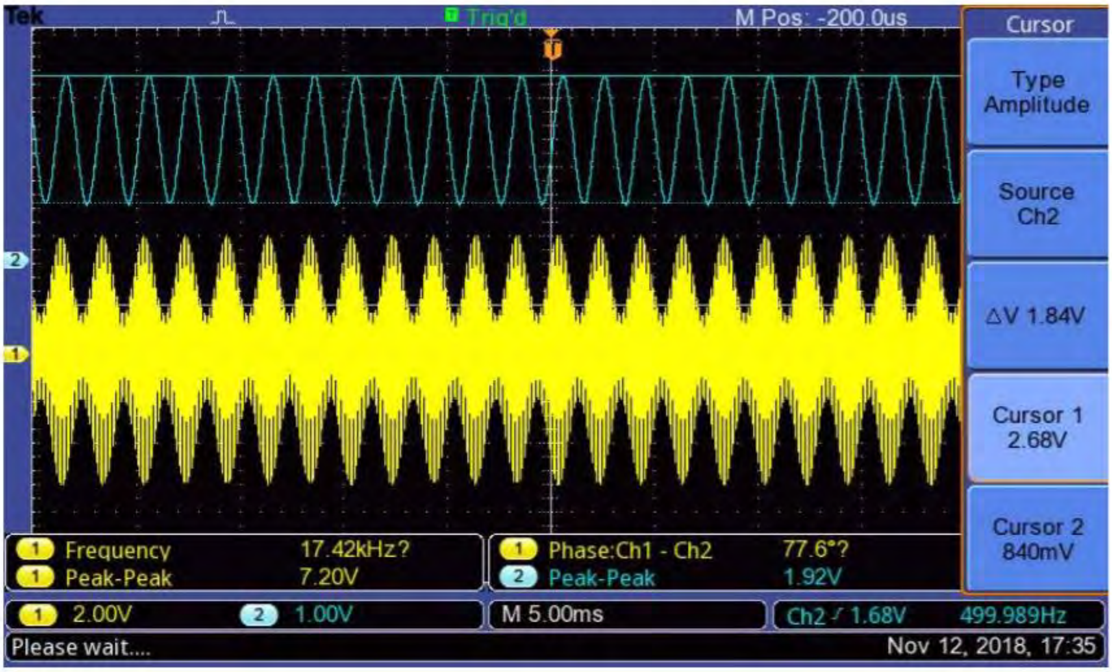
1.


Tek
Stop
M Pos: -200.0us
Ch2
Coupling
DC
BW Limit
On Off
70MHz
Volts/Div
Coarse
Probe
10X
Voltage
Invert
On Off
1 Frequency ?
1 Peak-Peak 7.68V
1 Phase:Ch1 - Ch2 ?
2 Peak-Peak 2.64V
1 2.00V
2 1.00V
M 1.00ms
Ch1 ⁄ 1.04V
15.5130kHz
Please wait....
Nov 12, 2018, 17:30

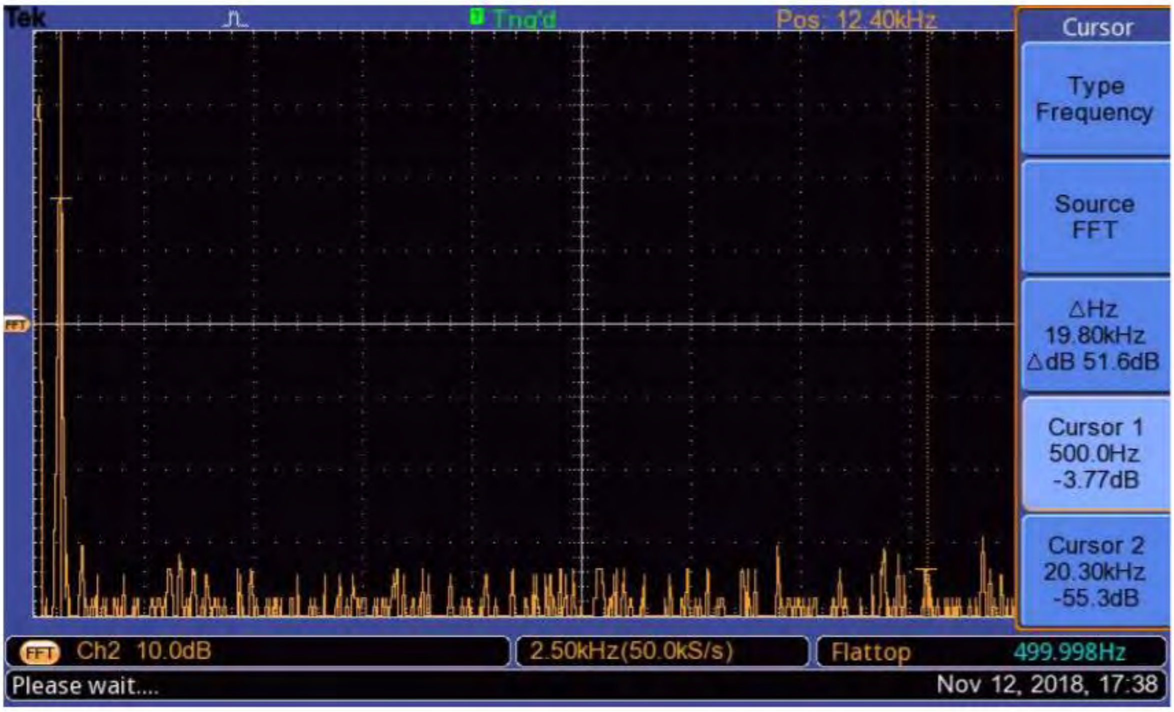
2.


Tek
Stop
M Pos: -200.0us
Ch2
Coupling
DC
BW Limit
On Off
70MHz
Volts/Div
Coarse
Probe
10X
Voltage
Invert
On Off
1 Frequency 19.95kHz?
1 Peak-Peak 7.52V
1 Phase:Ch1 - Ch2 94.4°?
2 Peak-Peak 1.92V
1 2.00V
2 1.00V
M 1.00ms
Ch1 ⁄ 1.04V
15.5129kHz
Please wait....
Nov 12, 2018, 17:31

3. Amplitude = 2.68V



4.



Here we can see from the cursor that at 20kHz there is no peak thus the carrier in our case is almost completely eliminated.

7.5.4 Evaluation

Problem 1: AM modulated Signals in Time Domain

In the lab report:

1. What is the relation between the modulation index and the relative magnitudes of the frequency components?

The AM modulation index is a measure based on the ratio of the modulation amplitude and the carrier amplitude. It is defined as:

$$m = \frac{\text{peak value of } m(t)}{A} = \frac{M}{A}$$

where M = modulation amplitude and A are the and carrier amplitude.
We derived the formulae in our pre-lab task

$$m = \frac{\mathrm{M}}{\mathrm{A}} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

2. Calculated the modulation index using the measurements! Compare to the index you have used to generate the AM signal.

The calculations were done previously in the execution part too

First part:

$$m = \frac{(7.52V - 2.56V)}{(7.52V + 2.56V)} = 0.4921$$
$$= 0.4921 \times 100\% = 49.21\% \approx 50\%$$

Second part:

$$m = \frac{(8.64V - 1.60V)}{(8.64V + 1.60V)} = 0.6875$$
$$= 0.6875 \times 100\% = 68.75\% \approx 70\%$$

Third part:

$$m = \frac{(11.4V + 1.00V)}{(11.4V - 1.00V)} = 1.1923$$
$$= 1.1923 \times 100\% = 119.23\% \approx 120\%$$

Theoretical and preset values are comparable and very closer to each other. There is only a difference of 1-2% which may be due to uncertainties(noise/resistances), limitations of the generator and the oscilloscope. These differences are due to instrument errors and reading errors.

3. Discuss the effect and the disadvantages of using a modulation index greater than 100

In the execution part, when we used modulation to be 120%, we saw spectrum change. We see overmodulation occur, and due to which we can no longer recover the original signal correctly. The message signal amplitude is bigger than the amplitude of the carrier signal, in the case of modulation index greater than 100%, which results in overlap between the sidebands when the signal is reaching its minimum value.
The ratio of the sideband power to total power is increased as compared to smaller indices. The recovery of the signal is impossible in this case since, the envelop crosses the mean. Therefore, information is lost when m >100%.

Problem 2: AM Modulated Signals in Frequency Domain

1. How does the spectrum look like in theory? Compare to the experiment!

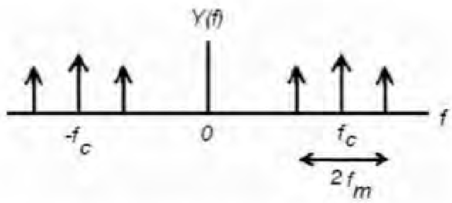
$$y(t) = A_c[1 + kA_m \cos(2\pi f_m t)] \cos(2\pi f_c t)$$

Where $m = k \times A_m$ and $m = \frac{\mathrm{Am}}{\mathrm{Ac}}$

$$\mathrm{y(t)} = [A_c + A_\mathrm{m}\mathrm{Cos}(\omega_\mathrm{m}\mathrm{t})] \cos(\omega_c\mathrm{t})$$

The peaks we get are:

$$\begin{aligned} Y(f) = &\frac{A_C}{2}[\delta(f - f_C) + \delta(f + f_C)] + \\ &\frac{mA_C}{4}[\delta(f - f_C - f_m) + \delta(f + f_C + f_m)] + \\ &\frac{mA_C}{4}[\delta(f - f_C + f_m) + \delta(f + f_C - f_m)] \end{aligned}$$



Using the trigonometric identities, we get the following equation:

y(t) = A_c (Cos(ω_ct)) +A_m/2 (cos(ω_c+ω_m)t) + A_m/2 (cos(ω_c− ω_m)t)

Thus, according to the equation and picture above, we should get a peak at 200KHz (peak of carrier frequency). We also get two sideband peaks, (200kHz- 1kHz) = 199kHz and one at (200kHz +1) = 201 kHz. Due to the two Am/2 parts in the equation.

For us we will get:

$A_C = 10^{Ac/20} * \sqrt{2} = 10^{11/20} * \sqrt{2} = 5.0178V$ (This is at peek voltage)

The two sidebands we got are the two terms (Am/2) given in our formulae. We use the above formulae to convert them in V_{RMS} and then multiply the result by 2 (because we have two sideband peaks).

As

$A_C = 2 * 10^{A_C/20} * \sqrt{2} = 2 * 10^{2.25/20} * \sqrt{2} = 3.664V$

2. Does the function generator generate a DSB or DSB-SC AM signal?

From the hard copies taken in the execution part, it can be seen that the function generator generates a DSB full carrier AM modulated signal. Throughout the execution we are able to conclude this answer from the time and frequency domain. In time domain, the shape of the envelop modulates exactly following the message signal. This is more visible in the frequency domain (FFT) where the spectrum shows the carrier frequency along with the two sidebands at the corresponding frequencies.

3. How does changing the carrier frequency affect the AM spectrum?

When the carrier frequency is increased, there is a shift of signal. It also means AM signal will be shifted to the right in the frequency domain and decreasing it will shift to the left.

$$Y(f) = \frac{A_c}{2}\left[\delta(f_m - f_c) + \delta(f_m + f_c) + \frac{kA_c}{2}\left(X(f_m - f_c) + X(f_m + f_c)\right)\right]$$

This equation dictates this logic.

The other frequency peaks remain the same and do not move.

4. How does changing the message frequency affect the AM spectrum?

When message frequency is changed, the frequency peaks of the sidebands are changed by shifting them in a frequency according to the changed message frequency. Also, the magnitudes in the spectrum remain unchanged.

5. Determine the modulation index m using the measured values

$$a = \frac{a_m}{A_C} = \frac{3.664}{5.017} \times 100 = 73\%$$

Problem 3: Demodulation of a message signal

1.Compare the 1. and 3. order filter output signal with the message signal. 2. Compare the measured signals with the MatLab results. What are the differences between simulation and measurement?

In first order output, the carrier wave is still there as seen in the execution part whereas in third order out, the carrier signal completely vanishes. This happens because, the first order filter causes the signal output amplitude to be lower than the input amplitude. Moreover, the cutoff frequency being 1000Hz is low, which means the signal is already damped.

2. Compare the measured signals with the MatLab results. What are the differences between simulation and measurement?

The Vpp of 3rd order filter is smaller than 1st order once but they are close. However, we see that the output amplitude is lower than the input one in the real circuit. The command filters works slightly different way than the built filter.

Reference

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