ASSIGNMENT TOP SHEET
University of Glasgow
Glasgow College UESTC

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Course Name: **Communications Principles and Systems**	Submission Deadline: **Friday, 2/12/2019**
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Course Coordinator: **Dr. Petros Karadimas**

Assignment Title:
Principles of Analogue Amplitude and Frequency Modulation

Section I. Introduction and theoretical analysis

A) Brief introduction

Modulation is the process of encoding information into a signal that can be transmitted (or recorded) over a channel of interest. In analog modulation, a baseband message signal, such as speech, audio or video, is directly transformed into a signal that can be transmitted over a designated channel. We study two broad classes of techniques: amplitude modulation, in which the analog message signal appears directly in the I and/or Q components; and angle modulation, in which the analog message signal appears directly in the phase or in the instantaneous frequency (i.e., in the derivative of the phase), of the transmitted signal. There are three main amplitude modulation techniques: Double Sideband (DSB) Suppressed Carrier (SC), Conventional AM and Single Sideband Modulation (SSB).

B) DSB-SC and conventional AM

i) Double Sideband (DSB) Suppressed Carrier (SC) modulation is to use the message m to modulate the I component of passband transmitted signal u. The expressions of DSB signal in time domain and frequency domain are as follows:

$$\mathrm{u}_{\mathrm{DSB}}(t) = Am(t)\cos(2\pi f_c t)$$

$$U_{DSB}(f) = \frac{A}{2}(M(f - f_c) + M(f + f_c))$$

As an example, consider a message signal as Figure 1. The spectrum of the passband DSB-SC signal for the example message is shown in Figure 2. The bandwidth of message m is B and the bandwidth of DSB-SC signal is twice the message bandwidth ($2B$). We can reconstruct the message since the Upper sideband (USB) lower sideband (LSB) of *u(t)* contain all the message information in frequency domain.

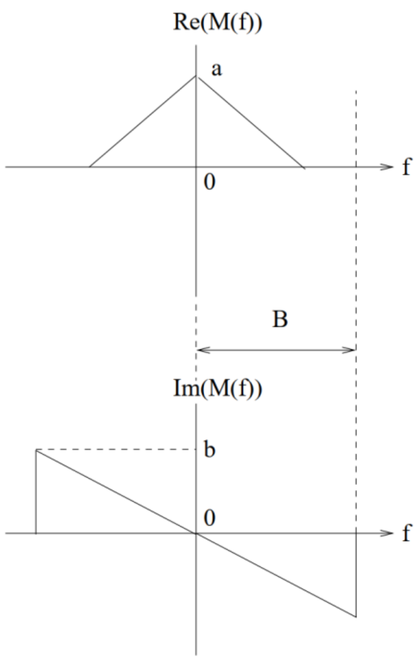


Figure 1

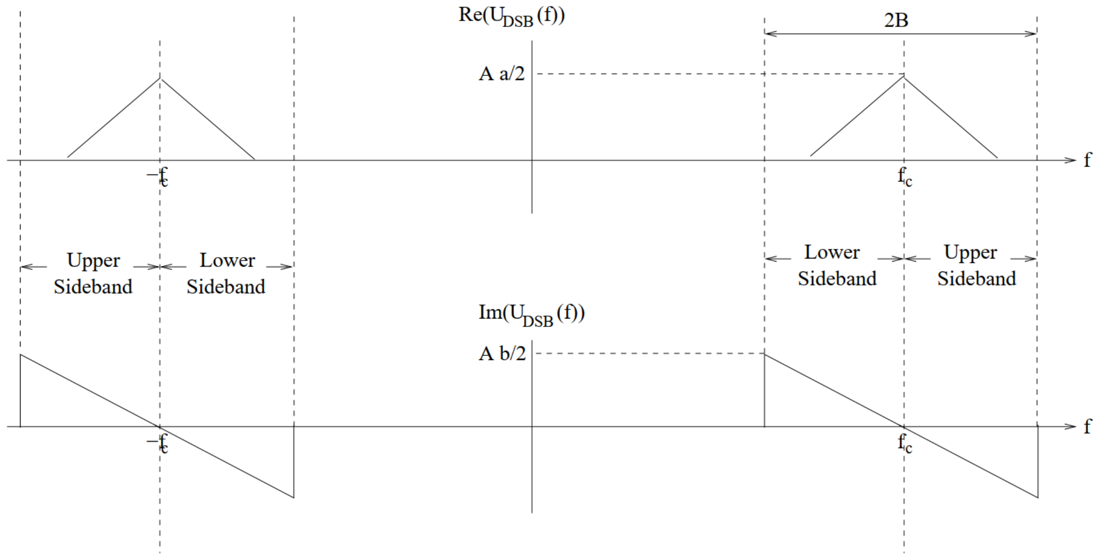


Figure 2

The term suppressed carrier is employed because there is no discrete component at the carrier frequency (i.e., *Up(f)* does not have impulses at $\pm f_c$).

ii) The conventional AM modulation is to add a large carrier component to a DSB signal, so the passband signal in time domain and frequency domain are shown as follows:

$$\mathrm{u_{AM}}(t) = Am(t)\cos(2\pi f_c t) + A_c \cos(2\pi f_c t)$$

$$\mathrm{U_{AM}}(f) = \frac{A}{2}\big(M(f - f_c) + M(f + f_c)\big) + \frac{A_c}{2}\left(\delta(f - f_c) + \delta(f + f_c)\right)$$

which means that, in addition to the USB and LSB due to the message modulation, we also have impulses at $\pm fc$ due to the unmodulated carrier. The spectrum of a conventional AM signal for the example message is shown in Figure 3.

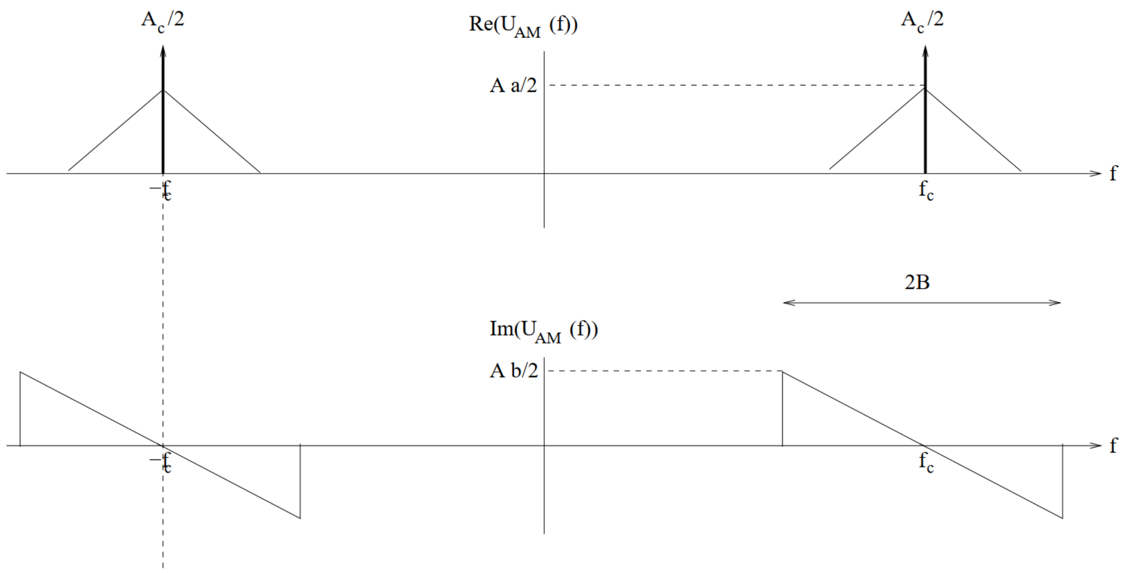


Figure 3

The envelop of the AM signal is given by:

$e(t) = |Am(t) + A_c|$

For correct envelope detection, we need

$$Am(t) + A_c \geq 0.$$

C) Frequency modulation (FM)

In FM, the message is contained in instantaneous frequency offset. For message m(t), we have

$$\frac{1}{2\pi}\frac{d\theta(t)}{dt} = f(t) = k_f m(t)$$

By integrating the expression above, we can get the phase of the FM wave form:

$$\theta(t) = 2\pi k_f \int_0^t m(\tau)d\tau$$

So, the FM signal is

$$\mathrm{v(t)} = \cos(2\pi \mathrm{f_c} + \theta(\mathrm{t})) = \cos(2\pi f_c + 2\pi \mathrm{k_f} \int_0^t m(\tau)d\tau)$$

The modulation index is defined as

$$\beta = \frac{\mathrm{k}_f \max_t |m(t)|}{B}$$

We use the term narrowband FM if β < 1 and the term wideband FM if β > 1. For narrowband FM, the bandwidth is about 2B. For wideband FM, the bandwidth of FM signal is

$$B_{FM} = 2B + 2\mathrm{k}_f \max_t |m(t)| = 2B(\beta + 1)$$

where B is the bandwidth of message m(t).

FM waveforms should have less abrupt phase transitions due to the smoothing resulting from integration.

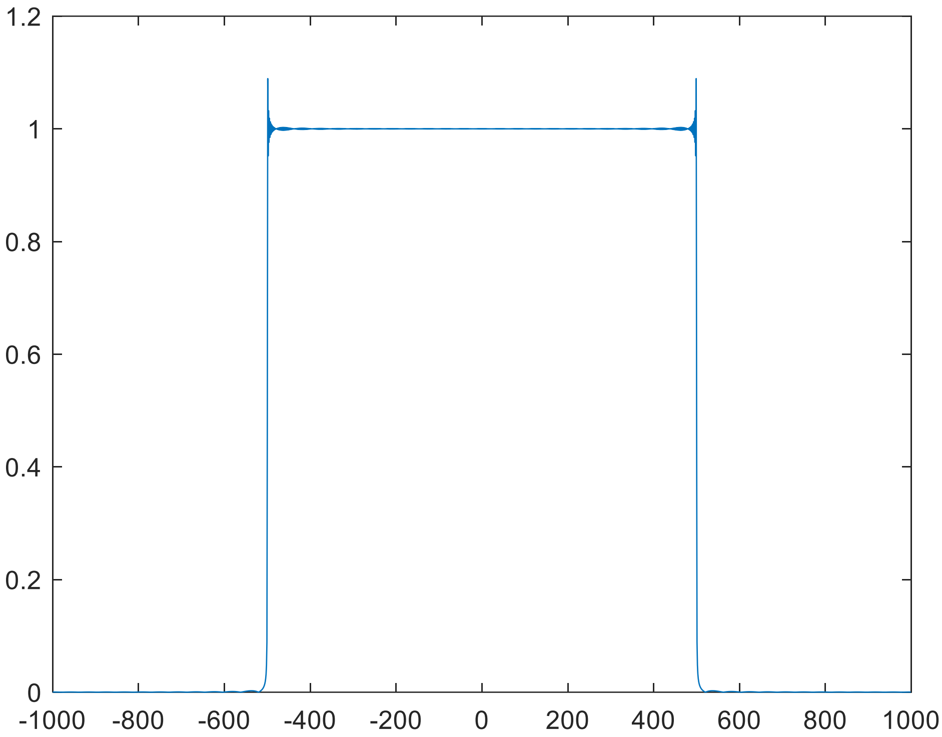
Section II. Experiment Results

A) The bandwidth of

$$m(t) = \frac{1}{T}\sin c(\frac{t}{T}):$$

$$\frac{1}{T}\sin c(\frac{t}{T}) \leftrightarrow \begin{cases} 1, |\omega| < \dfrac{\pi}{T} \\ 0, |\omega| > \dfrac{\pi}{T} \end{cases}, T = 0.001$$

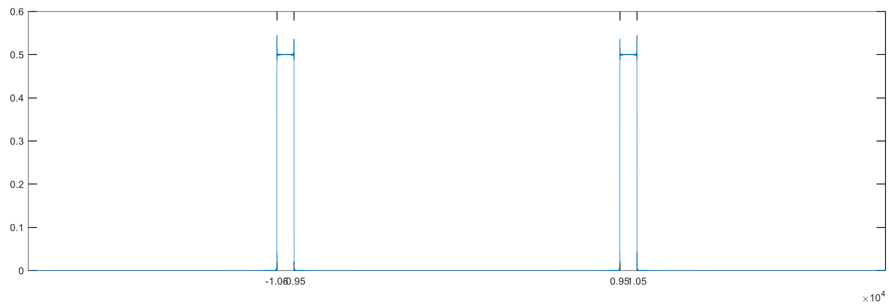
where f=1/T=500Hz. Therefore, the bandwidth is 500. The figure below shows the correctness of this result.



B) Consider the DSB AM signal

$$u(t) = m(t)\cos(2\pi f_c t), f_c = 10/T$$

u(t) is the DSB modulation of *m(t)*. Therefore, the bandwidth should be twice of the bandwidth of message, which is 1000 *Hz.* The spectrum is shown below and the bandwidth is obviously 1000 *Hz.*



(A_c=0)

Comparing the spectra of *m(t)* and *u(t)*, we can see that the shape of DSB signal for positive frequency and negative frequency are just the same with the spectra of message signal, which means that the DSB contains two components centered at $f_c = 10^4$ which are exactly the same with the message spectra.

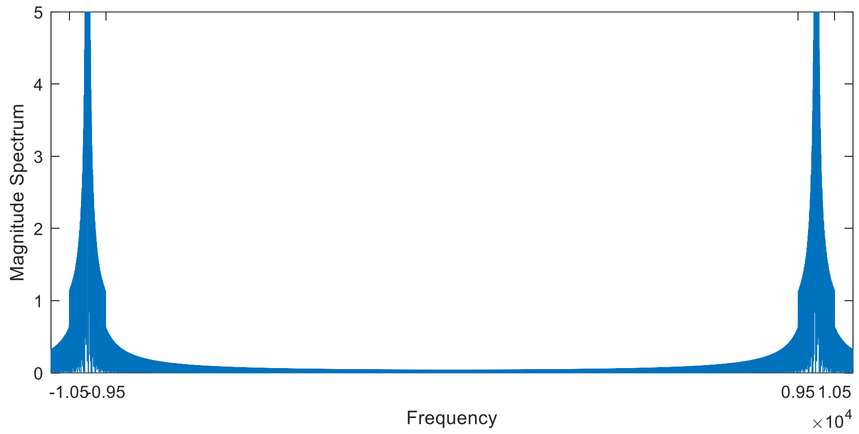
C) Consider the conventional AM signal

$$u_{AM}(t) = [A_c + m(t)]\cos(2\pi f_c t), f_c = 10/T$$

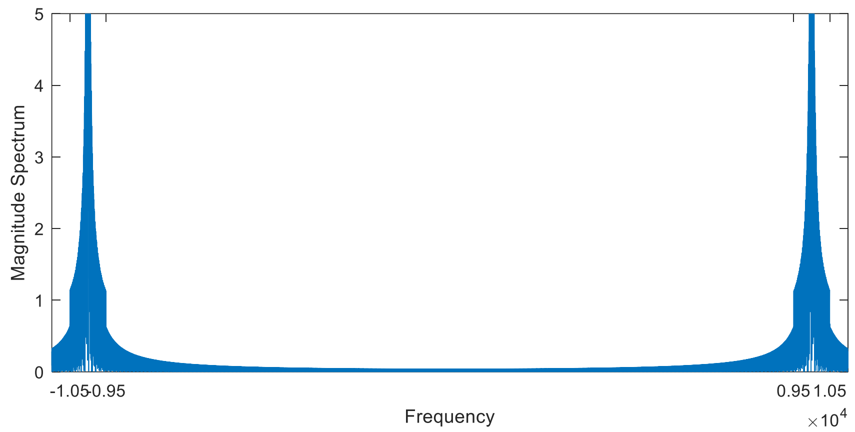
Choose A_c to have the smallest possible value in order to detect envelope correctly. The bandwidth of u_{AM} is twice of the bandwidth of message signal, which is also 1000 Hz. In order to detect envelope correctly, it should satisfy:

$$A_{c\min} \geq |m(t)|$$

Therefore, $A_{c\min}$=1000. The plots of u_{AM} when A_c=1000 and A_c=2000 are shown below. When A_c=0, the spectra is the same as *u(t)* above. We can see the bandwidth of both signals are roughly 1000, which did not change as A_c changes. Since there are two impulse at 10^4 Hz and -10^4 Hz, the spectra of DSB and conventional AM are definitely different.

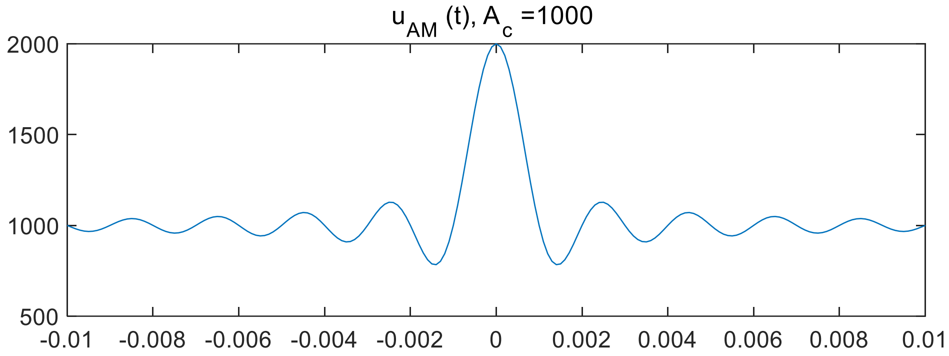


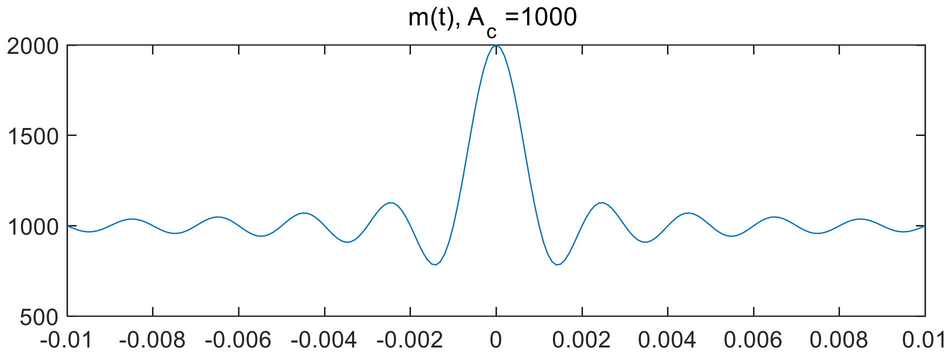
A_c=1000

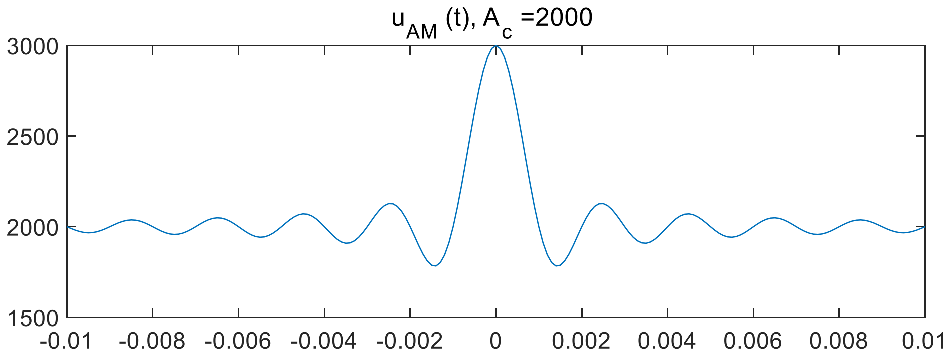


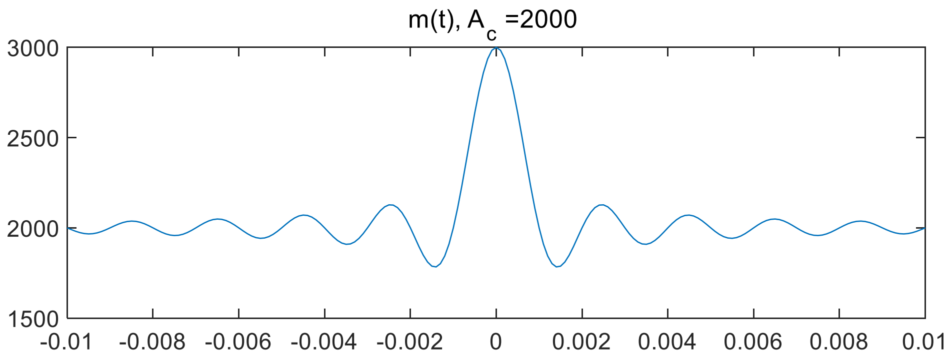
A_c=2000

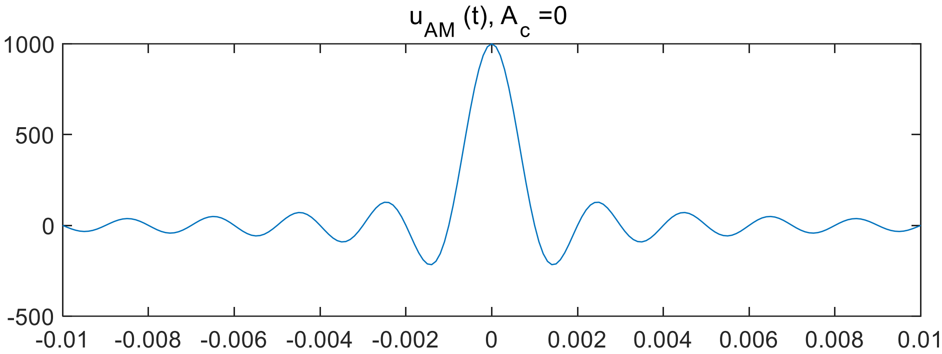
We do the envelope detection for A_c=1000, 2000 and 0, respectively.

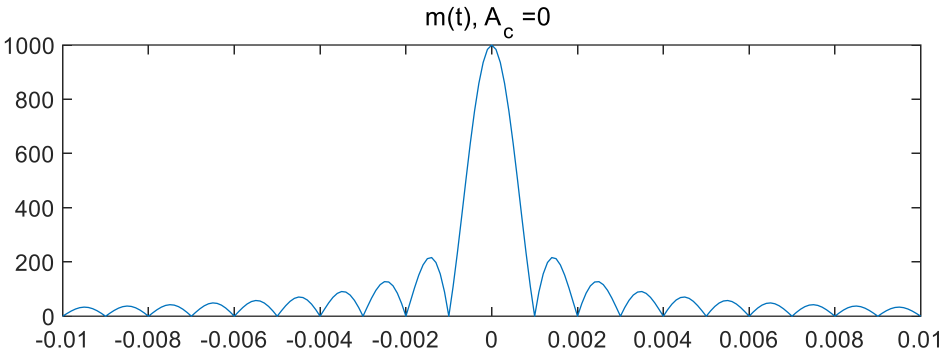

$u_{AM}(t)$, A_c =1000
2000
1500
1000
500
-0.01 -0.008 -0.006 -0.004 -0.002 0 0.002 0.004 0.006 0.008 0.01


m(t), A_c =1000
2000
1500
1000
500
-0.01 -0.008 -0.006 -0.004 -0.002 0 0.002 0.004 0.006 0.008 0.01


$u_{AM}(t)$, A_c =2000
3000
2500
2000
1500
-0.01 -0.008 -0.006 -0.004 -0.002 0 0.002 0.004 0.006 0.008 0.01


m(t), A_c =2000
3000
2500
2000
1500
-0.01 -0.008 -0.006 -0.004 -0.002 0 0.002 0.004 0.006 0.008 0.01





We find that when A_c=0, the message signal is below zero from time to time, which lead to the difference between the original message signal and signal derived.

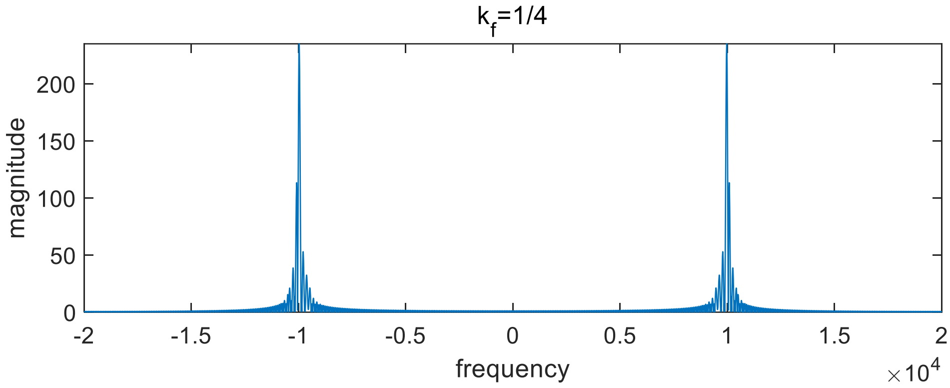
D) Consider the FM signal

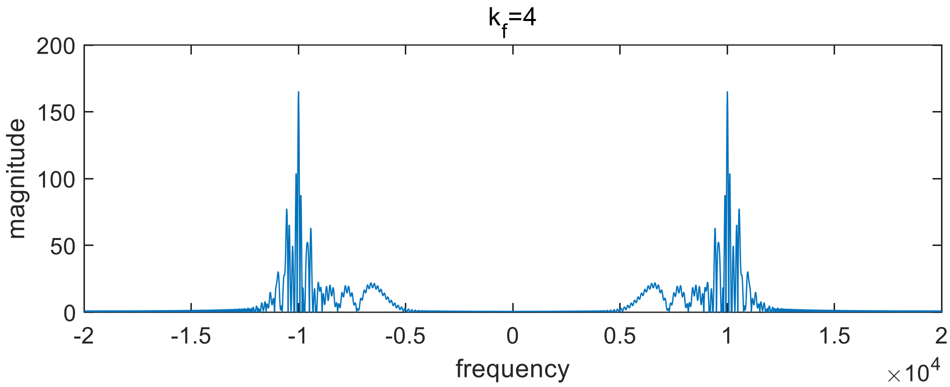
$$v(t) = \cos[2\pi f_c t + \theta(t)], \theta(t) = 2\pi k_f \int_0^t m(\tau)d\tau, f_c = 10/T$$

From the plot below, we can find the bandwidth as 1500 Hz when k_f =1/4 and 9000 Hz when k_f =4, approximately. In terms of Carson's formula

$$B_{FM}\text{=}2B\text{+}2\text{k}_f \max_t |m(t)| = 2B(\beta+1)$$

When k_f is 1/4, B_{FM} =1000+1000/2=1500 Hz. When k_f =4, B_{FM} =9000 Hz, which is as same as what figures show.





Comparing about these figures, we could reach the conclusion that the bandwidth of AM signal does not change with other factors expect the bandwidth of message. It is always twice as much as the bandwidth of message. However, the bandwidth of FM signal can be affected by the selection of k_f .

In order to get the correct signal, the necessary condition is to let k_f <9/2, since the components do not overlap each other and the bandwidth of message is 500, the spectra should be centered on $\pm 10^4$ or more .

Section III. Conclusion

In this lab session, we firstly learned the main modulation techniques of DSB and conventional AM and FM, then we tried to describe and execute them in MATLAB. Several ways of modulation were carried out based on a message signal *m(t)* and the rules of the change of bandwidth. During this process, we have got more familiar to the AM and FM modulation techniques applied in communication system and also the manipulation of MATLAB.

Section IV. Reference

U. Madhow, “Introduction to Communincation Systems,” Cambridge University Press, 2014

Appendix: my code

A)

```
ts=0.0005;
time_interval = -0.5:ts:0.5;
T=0.001;
signal_timedomain=(1/T).*sinc(time_interval./T);
fs_desired = 1;
Nmin = ceil(1/(fs_desired*ts));
Nfft = 2^(nextpow2(Nmin));
signal_freqdomain = ts*fft(signal_timedomain,Nfft);
signal_freqdomain_centered = fftshift(signal_freqdomain);
fs=1/(Nfft*ts);
freqs = ((1:Nfft)-1-Nfft/2)*fs;
plot(freqs,abs(signal_freqdomain_centered));
xlabel('Frequency');
ylabel('Magnitude Spectrum');
```

B)

```
ts=1/50000;
time_interval = -0.5:ts:0.5;
T=0.001;
m_t=(1/T).*sinc(time_interval./T);
f_c=10/T;
signal_timedomain =m_t.*cos(2*pi*f_c.*time_interval);
fs_desired = 1;
Nmin = ceil(1/(fs_desired*ts));
Nfft = 2^(nextpow2(Nmin));
signal_freqdomain = ts*fft(signal_timedomain,Nfft);
signal_freqdomain_centered = fftshift(signal_freqdomain);
fs=1/(Nfft*ts);
freqs = ((1:Nfft)-1-Nfft/2)*fs;
plot(freqs,abs(signal_freqdomain_centered));
set(gca, 'XTick', [ -10500 -9500 9500 10500])
```

C)

```
ts=1/50000;
time_interval = -0.5:ts:0.5;
```

```
T=0.001;
m_t=(1/T).*sinc(time_interval./T);
f_c=10/T;
signal_timedomain =(m_t+1000).*cos(2*pi*f_c.*time_interval);
fs_desired = 1;
Nmin = ceil(1/(fs_desired*ts));
Nfft = 2^(nextpow2(Nmin));
signal_freqdomain = ts*fft(signal_timedomain,Nfft);
signal_freqdomain_centered = fftshift(signal_freqdomain);
fs=1/(Nfft*ts);
freqs = ((1:Nfft)-1-Nfft/2)*fs;
plot(freqs,abs(signal_freqdomain_centered));
set(gca, 'XTick', [ -10500 -9500 9500 10500])
xlabel('Frequency');
ylabel('Magnitude Spectrum');


ts=1/50000;
time_interval = -0.5:ts:0.5;
T=0.001;
m_t=(1/T).*sinc(time_interval./T);
f_c=10/T;
signal_timedomain =(m_t+2000).*cos(2*pi*f_c.*time_interval);
fs_desired = 1;
Nmin = ceil(1/(fs_desired*ts));
Nfft = 2^(nextpow2(Nmin));
signal_freqdomain = ts*fft(signal_timedomain,Nfft);
signal_freqdomain_centered = fftshift(signal_freqdomain);
fs=1/(Nfft*ts);
freqs = ((1:Nfft)-1-Nfft/2)*fs;
plot(freqs,abs(signal_freqdomain_centered));
set(gca, 'XTick', [ -10500 -9500 9500 10500])
xlabel('Frequency');
ylabel('Magnitude Spectrum');


T=0.001;
f_c=10/T;
t=-0.01:0.0001:0.01;
m=1000.*sinc(1000.*t);
u=(m+A_c).*cos(2*pi*f_c.*t);% A_c could be changed to 1000,2000,0
subplot(2,1,1)
```

```
plot(t,u)
title('u_A_M (t), A_c = ');% A_c could be changed to 1000,2000,0
subplot(2,1,2)
plot(t,abs(u))
title('m(t), A_c = ');% A_c could be changed to 1000,2000,0
```

D)

```
syms tao t;
kf_1=1/4;
kf_2=4;
T=0.001;
m=1000.*sinc(1000*tao);
theta1=2*pi.*kf_1*(int(m,'tao',0,t));
theta2=2*pi.*kf_2*(int(m,'tao',0,t));
v1=cos(2*pi*10000.*t+theta1);
v2=cos(2*pi*10000.*t+theta2);
t = (-2*pi/1000:0.25/10^4:2*pi/1000);
v_1=double(subs(v1));
v_2=double(subs(v2));
V1=fft(v_1,40000);
V2=fft(v_2,40000);
subplot(2,1,1)
plot(-20000:1:19999,abs(V1))
xlabel("frequency")
ylabel("magnitude")
title("k_f=1/4")
subplot(2,1,2)
plot(-20000:1:19999,abs(V2))
title('k_f=4')
xlabel('frequency')
ylabel('magnitude')
```