3TR4: Communication Systems
Lab 2

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Part 1: Plotting the message signal in time and frequency domain

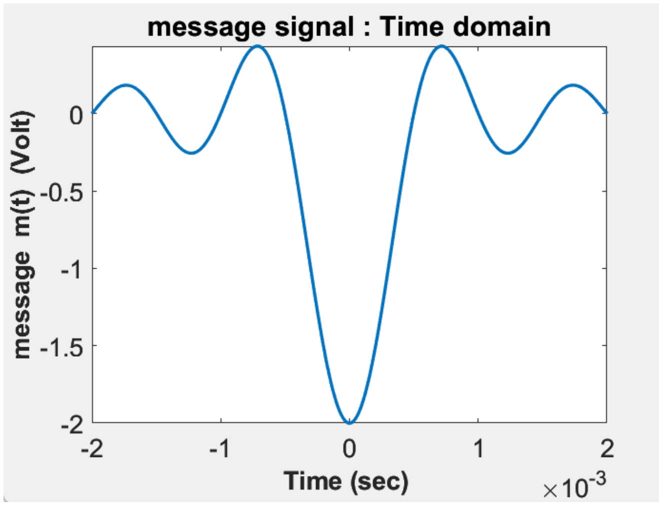

Figure 2. Message signal in the time domain

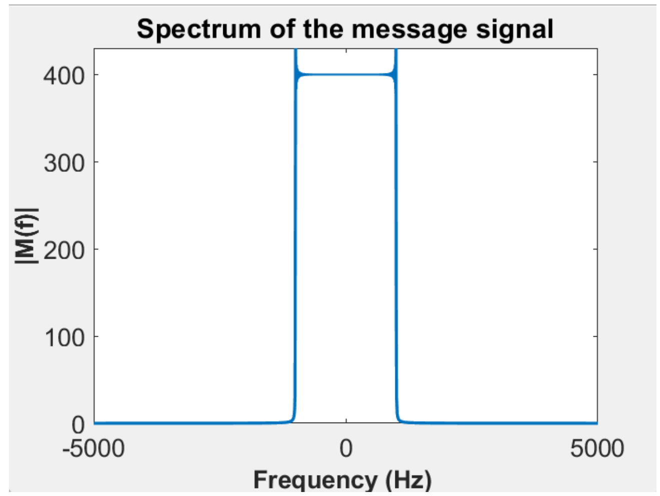

Figure 1. Message signal in the frequency domain

Analytical Calculations

$$m(t) \Leftrightarrow M(f)$$

$$sinc(t) \Leftrightarrow rect(f)$$

Using the scaling property

$$sinc\left(\frac{t}{Tm}\right) \Leftrightarrow Tm * rect(f * Tm)$$

$$-2 * sinc\left(\frac{t}{Tm}\right) \Leftrightarrow -2 * Tm * rect(f * Tm)$$

$$M(f) \Leftrightarrow -2 * Tm * rect(f * Tm)$$

As we know from the lab manual, Tm = 0.0005. If we put the function on the origin, we can that f = 1 and do 1/0.0005 = 2000. This means the message signal ranges from -1000 to 1000 and the highest frequency should occur at 1000Hz. Looking at the plot above, we can see that this aligns with our analytical calculations.

Part 2: Plotting the modulated signal in time and frequency domain

These are the plots with a 50% modulation.

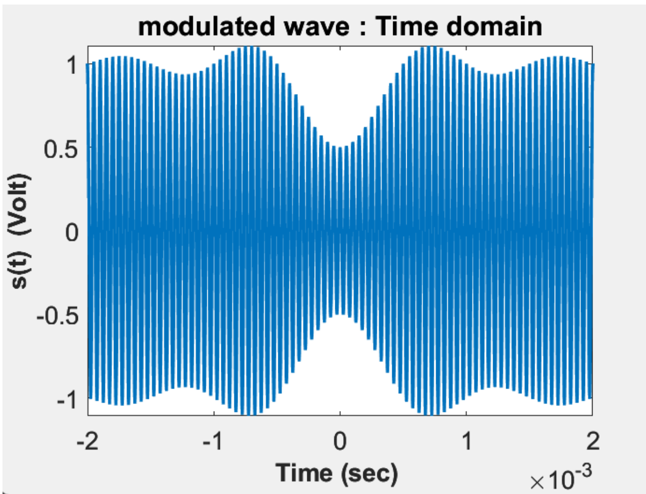

Figure 4. Modulated signal in the time domain.

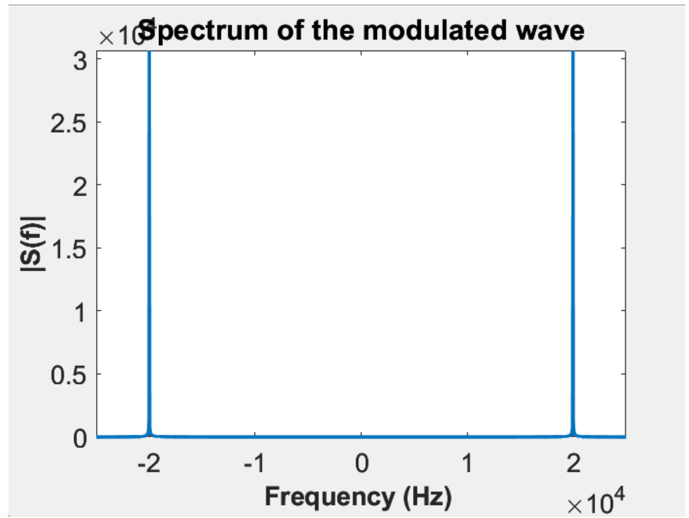

Figure 3. Modulated signal in the frequency domain.

Part 2i: Plotting the envelope detector and DC removal with a constant of RC = 1/fc

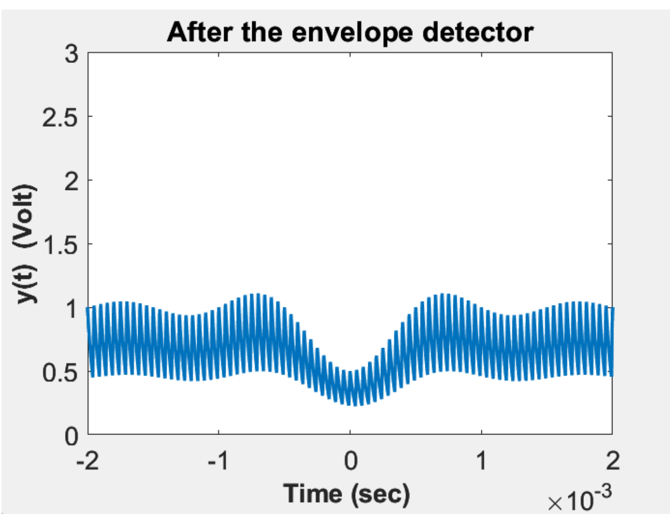

Figure 6. Envelope Detector

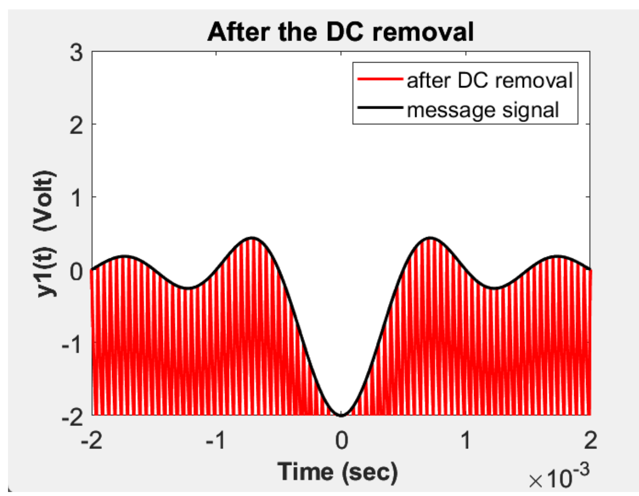

Figure 5. DC Removal

Looking at the ripple, we can see that there is a large influx in the output. We cannot represent the message signal accurately because of the influx. This happens because the capacitor discharges at a very fast rate.

Part 2ii: Plotting the envelope detector and DC removal with a constant of RC = 10Tm

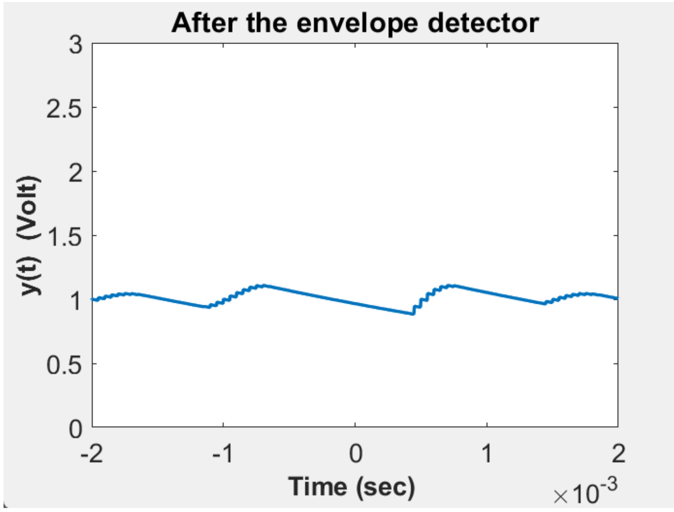

Figure 8. Envelope Detector

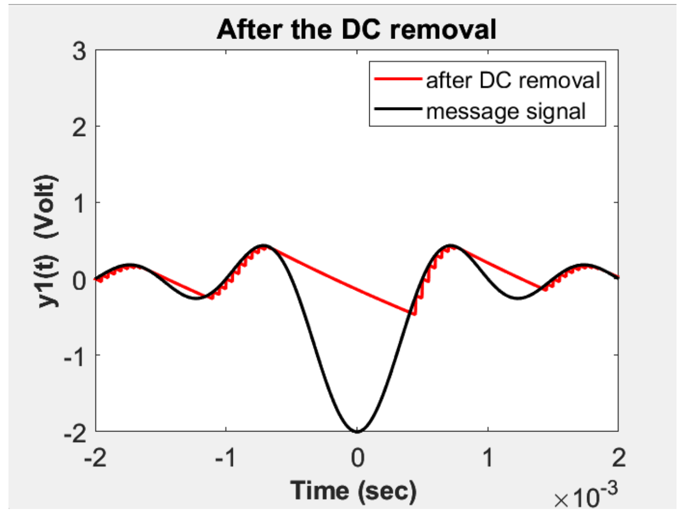

Figure 7. DC Removal

The signal presented after the DC removal does not resemble the one seen in the message signal. The RC value is 0.005 with the message signal giving a RC value of 0.000525. We can see that the RC value constant is much larger, and the capacitor will not be able to discharge at a rate to have no fluctuations in our plot.

Part 2iii: Plotting the envelope detector and DC removal with a constant of RC = ??.

Since we want our value to resemble the values given in the message signal, we looked at lecture 4 notes from Dr. Chen and found that the range for this is $\frac{1}{fc} \ll R_L C \ll \frac{1}{Fm}$.

We know that Fc = 20000 and Fm = 1000. Now we know that RC must be a value between 0.00005 and 0.001. We will make RC = 0.0005 or 0.5/Fm.

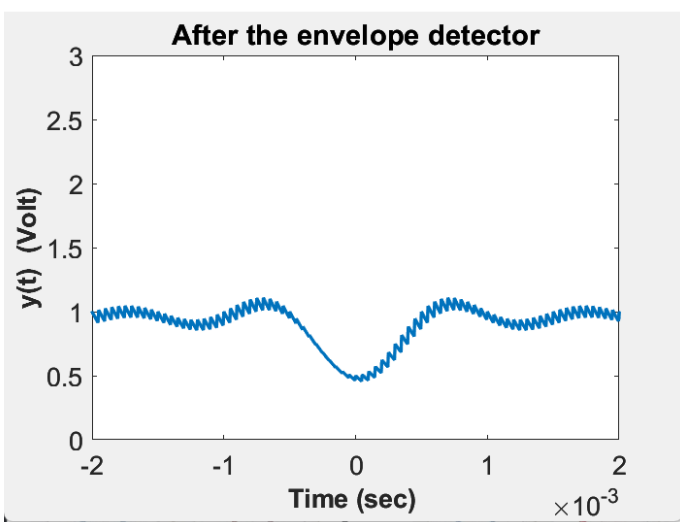

Figure 9. Envelope Detector

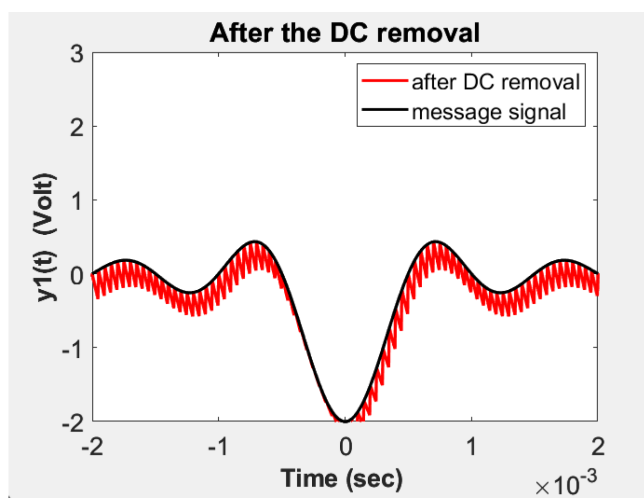

Figure 10. DC Removal

Part 3: Modulation changed to 200%

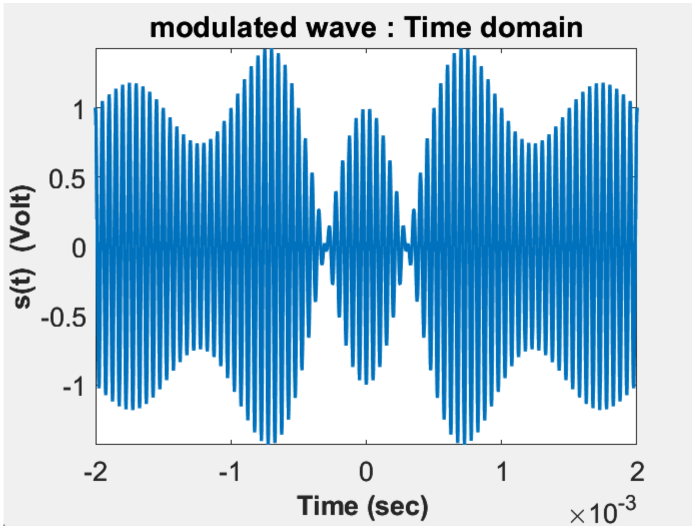

Figure 13. Modulated signal in the time domain at 200% modulation.

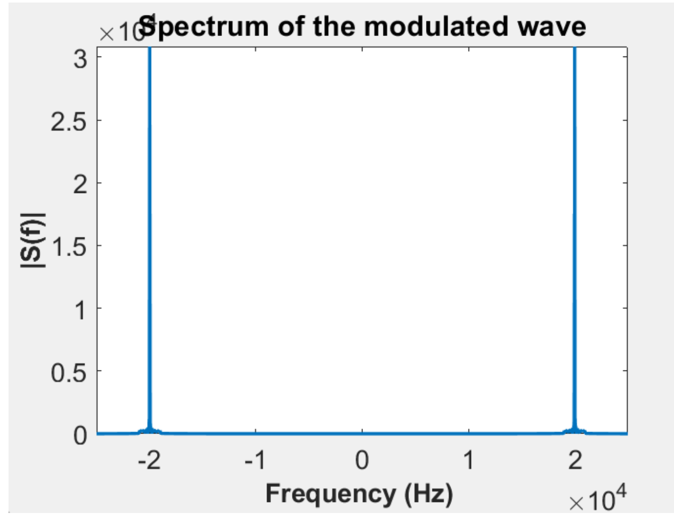

Figure 11. Modulated signal in the frequency domain at 200% modulation.

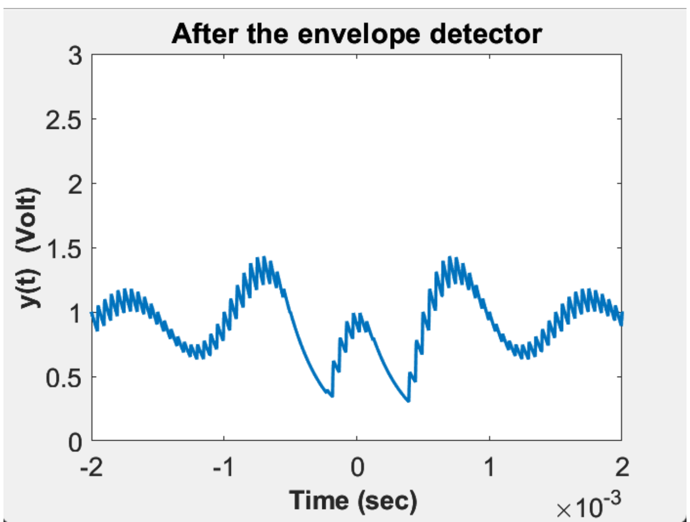

Figure 14. Envelope Detector at 200% modulation

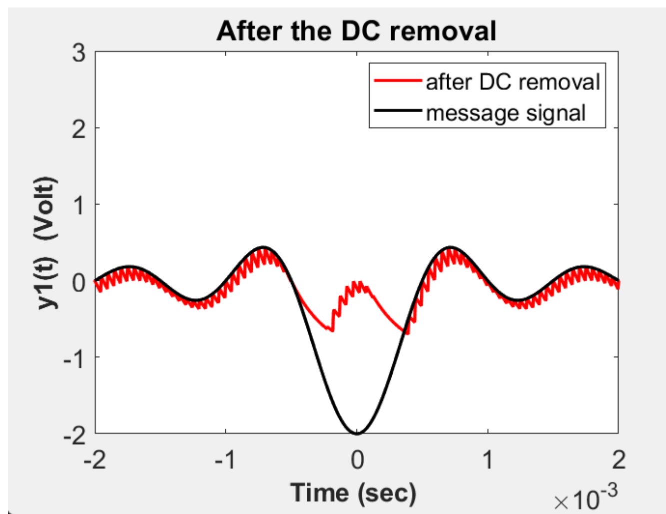

Figure 12. DC Removal at 200%

The images above show that the message signal can still be retrieved. However, the 200% modulation causes a bit of distortion which comes from the $[1+k_am(t)]$ component of the signal. In order to avoid distortion, we would need to separate the upper and lower envelope, so they are easily distinguishable. This can be done by choosing a value of k_a that satisfies.

$$|k_am(t)|<= 1$$

This ensures that there is no negative component after applying the DC offset of 1. For this scenario, there will be negative components when modulation is greater than 100%. For our equation, our m(t) = -2. Furthermore, when calculating for Ka at 200% modulation, the equation is %mod/maxmt. This gives us the equation 2/2 = 1. Now we have our ka and m(t) value. If we do the math 1*2 = 2. This makes sense because we are at a 200% modulation, so the value expected is <= 2 instead of <= 1. The result of this will ensure than with an offset, the entire function is positive and there will be no overlap in the envelopes (no reflection along the x-axis). Therefore, the upper envelope would be an accurate representation of the following function and can be used to retrieve the signal. However, this can only be done after DC removal is applied to the message signal.

Matlab

```
clear
hold off
format long e

% time samples
N = 2^16; %No. of FFT samples
sampling_rate = 40e4; %unit Hz
tstep = 1/sampling_rate;
tmax = N*tstep/2;
tmin = -tmax;
tt = tmin:tstep:tmax-tstep;

%freq samples
fmax = sampling_rate/2;
fmin = -fmax;
fstep = (fmax-fmin)/N;
freq = fmin:fstep:fmax-fstep;

%% Modulation

%carrier
fc=20e3;
Ac = 1;
ct=Ac*cos(2*pi*fc*tt);

%message signal
% Updated value of Am with given value in lab manual
Am=-2;
fm = 1e3;
% Create tm and updated the message signal to the values given in the lab manual
tm = 0.0005;
mt = Am*sinc(tt/tm);

%max of absolute of m(t)
maxmt = max(abs(mt));
%For 200% modulation
ka=2/maxmt;

%AM signal
st = (1+ka*mt).*ct;

% Carrier Signal, Time Domain
figure(1)
Hp1 = plot(tt,ct);
set(Hp1,'LineWidth',2)
Ha = gca;
set(Ha,'Fontsize',16)
Hx=xlabel('Time (sec) ');
set(Hx,'FontWeight','bold','Fontsize',16)
Hx=ylabel('Carrier c(t)  (Volt)');
set(Hx,'FontWeight','bold','Fontsize',16)
title('Carrier : Time domain');
axis([-1e-3 1e-3 -1.1 1.1])
pause(1)

% Message Signal Time domain
figure(2)
Hp1 = plot(tt,mt);
set(Hp1,'LineWidth',2)
Ha = gca;
set(Ha,'Fontsize',16)
Hx=xlabel('Time (sec) ');
set(Hx,'FontWeight','bold','Fontsize',16)
Hx=ylabel('message  m(t)  (Volt)');
set(Hx,'FontWeight','bold','Fontsize',16)
title('message signal : Time domain');
axis([-2e-3 2e-3 min(mt) max(mt)])
pause(1)

% Modulated Signal, Time domain
figure(3)
Hp1 = plot(tt,st);
```

```
set(Hp1,'LineWidth',2)
Ha = gca;
set(Ha,'Fontsize',16)
Hx=xlabel('Time (sec) ');
set(Hx,'FontWeight','bold','Fontsize',16)
Hx=ylabel('s(t)  (Volt)');
set(Hx,'FontWeight','bold','Fontsize',16)
title('modulated wave : Time domain');
axis([-2e-3 2e-3 min(st) max(st)])
pause(1)

% Spectrum of Message signal
Mf1 = fft(fftshift(mt));
Mf = fftshift(Mf1);
figure(4)
Hp1=plot(freq,abs(Mf));
set(Hp1,'LineWidth',2)
Ha = gca;
set(Ha,'Fontsize',16)
Hx=xlabel('Frequency (Hz) ');
set(Hx,'FontWeight','bold','Fontsize',16)
Hx=ylabel('|M(f)|');
set(Hx,'FontWeight','bold','Fontsize',16)
title('Spectrum of the message signal');
axis ([-5e3 5e3 0 max(abs(Mf))])
%pause(5)

% Spectrum of Modulated signal
Sf1 = fft(fftshift(st));
Sf = fftshift(Sf1);
figure(5)
Hp1=plot(freq,abs(Sf));
set(Hp1,'LineWidth',2)
Ha = gca;
set(Ha,'Fontsize',16)
Hx=xlabel('Frequency (Hz) ');
set(Hx,'FontWeight','bold','Fontsize',16)
Hx=ylabel('|S(f)|');
set(Hx,'FontWeight','bold','Fontsize',16)
title('Spectrum of the modulated wave');
axis ([-25e3 25e3 0 max(abs(Sf))])
%pause(5)

%% Demodulation

%time constant RC
%This should be optimized to avoid envelope distortion
% Part 2i
%RC = 1/fc

% Part 2ii
%RC = 10*tm;

% Part 2iii
%RC = 0.0005;

%RC = 0.5*(1/fc + 1/fm);

%Part 3
RC = 0.5*(tm + 1/fc);


%Envelope detector
yt = st;
n=1;
for t=tt
    if(n > 1)
        if(yt(n-1) > st(n))
            yt0 = yt(n-1);
            %time when C starts discharging
```

```
            tc = tt(n-1);
            yt(n) = yt0*exp(-(t-tc)/RC);
        end
    end
    n=n+1;
end
yt(1)=yt(2);


figure(6)
Hp1 = plot(tt,yt);
set(Hp1,'LineWidth',2)
Ha = gca;
set(Ha,'Fontsize',16)
Hx=xlabel('Time (sec) ');
set(Hx,'FontWeight','bold','Fontsize',16)
Hx=ylabel('y(t)  (Volt)');
set(Hx,'FontWeight','bold','Fontsize',16)
title('After the envelope detector');
axis([-2e-3 2e-3 0 3])
pause(1)
figure(7)

%DC removal and division by ka
yt1 = (yt - 1)/ka;
Hp1 = plot(tt,yt1,'r',tt,mt,'k');
legend('after DC removal','message signal')
set(Hp1,'LineWidth',2)
Ha = gca;
set(Ha,'Fontsize',16)
Hx=xlabel('Time (sec) ');
set(Hx,'FontWeight','bold','Fontsize',16)
Hx=ylabel('y1(t)  (Volt)');
set(Hx,'FontWeight','bold','Fontsize',16)
title('After the DC removal');
```

```
%pause

%Low pass filter to remove the ripple
%choose the cutoff frequency of the filter to be slightly higher than
%the highest freq of the message signal
% f0 = 1.1*fm;
% mt1 = rect_filt(yt1,freq,f0);
% figure(8)
% Hp1 = plot(tt,mt1);
% set(Hp1,'LineWidth',2)
% Ha = gca;
% set(Ha,'Fontsize',16)
% Hx=xlabel('Time (sec) ');
% set(Hx,'FontWeight','bold','Fontsize',16)
% Hx=ylabel('m1(t)  (Volt)');
% set(Hx,'FontWeight','bold','Fontsize',16)
% title('After the low pass filter');
% axis([-2e-3 2e-3 min(mt1) max(mt1)])
```