EECS 455: Solutions to Problem Set 6

1. Consider a GPS communication system that transmits signals from satellites. The signals correspond to various Gold codes. Data from the satellites has been recorded and is saved in a file on the C-tools web site (called gpsdata). When you load this into Matlab you will have a vector called rt that represents samples of the received signal (these are actually samples that have been down converted, and quantized) with two samples per chip. The total data file has $N = 2^{20}$ samples. For each satellite spreading code filter the received samples with a filter matched to the spreading code over 1 msec (1023 chip) period. Then take the absolute value (magnitude) of the complex signal and filter the resulting signal with a filter that results in adding 20 samples spaced by 1 msec each (or 1023 chips or 2046 samples). Determine at least two satellites that produce a significant signal output. Find the corresponding phase shift over time and thus the Doppler shift.

   Solution:

   The received signal is first filtered with a filter matched to the spreading codes of each of the satellites. The absolute value is taken of the result. The figures below display the absolute value for a couple different satellites. Figure 1 shows the signal over a wide range of samples and shows the signal is present for .3 seconds and afterwords the signal is just 0. Figure 2 is the same but with the time scale reduced to the interval [0 .04]. Figure 3 is the output for satellite 18. Figure 4 shows the real and imaginary components of the samples of satellite 18. Figure 5 shows the change in phase of consecutive samples (spaced 1 msec apart). Mostly the change in phase is about 1.8 but sometimes the change in phase is about -1.3. The samples with a change of phase of -1.3 correspond to the data bit changing from one sample to the next sample. This causes a π phase change in the sample values. We can compensate for these data bit transitions by adding π to the phase changes of this satellite that are less than 0. Similar results for satellites 21 is shown in Figures 6, 7,8. Notice that in Figure 8 there appear to be three distinct phases, namely about 3, 0 and -3. However, 3 and -3 are essentially the same phase, whereas 0 corresponds to a π phase change. Again we can manipulate these phase changes and averge the phase change over the different samples to get an average phase change. Once the average phase change is determined we can determine the Doppler frequency by

$$\hat{f}_D = \frac{\bar{\Delta\phi}}{2\pi T}$$

   where T is the time between samples (1msec) and $\bar{\Delta\phi}$ is the average phase. For satellite 18 and 21 we obtain

$$\begin{aligned} f_d(18) &= 281Hz \\ f_d(21) &= 463Hz \end{aligned}$$

   If your answer is within ± 5 % you will get credit for this.

```
%  This program simulates a DS BPSK modulator at baseband.
```

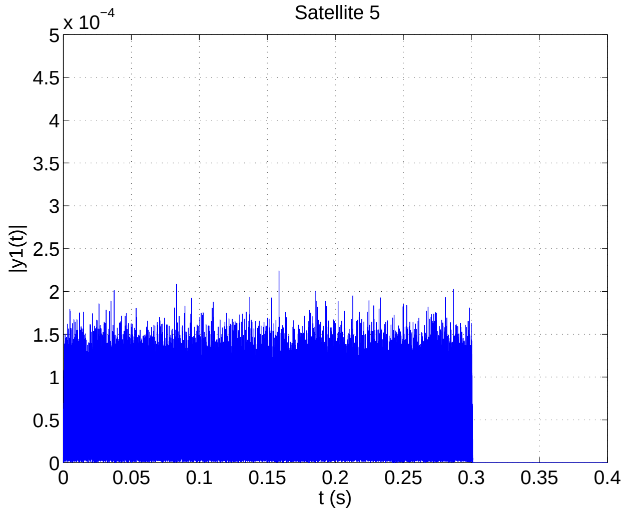

Figure 1: Signal from a satellite without a obvious signal component

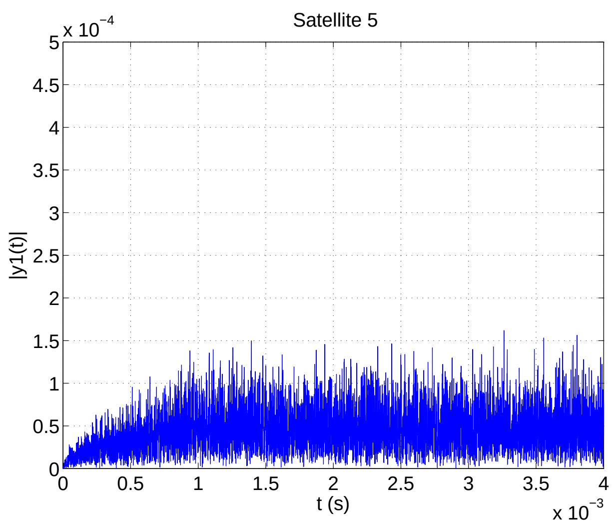

Figure 2: Signal from a satellite without a obvious signal component (zoomed in)

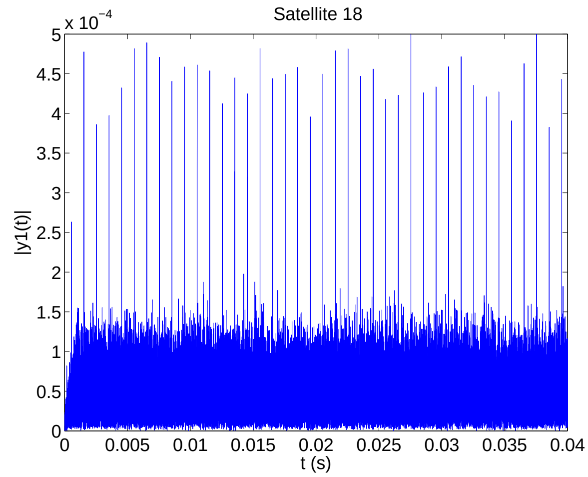

Figure 3: Signal from a satellite with a clear signal component

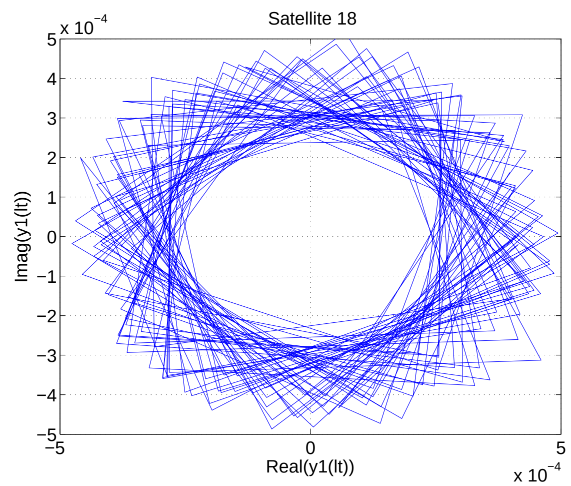

Figure 4: Phase of samples of the signal from a satellite 18

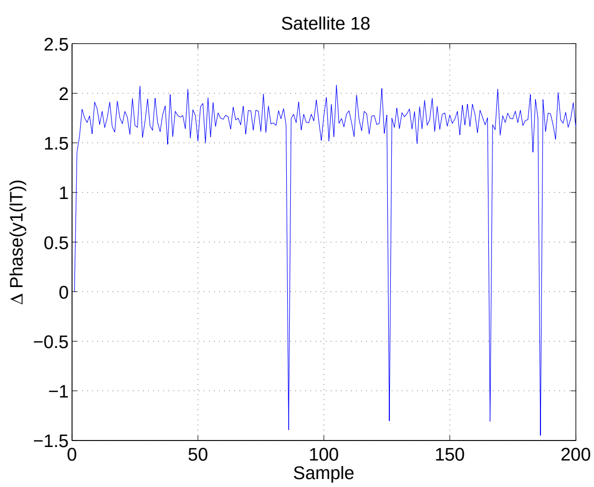

Figure 5: Change of phase of samples of the signal from a satellite 18

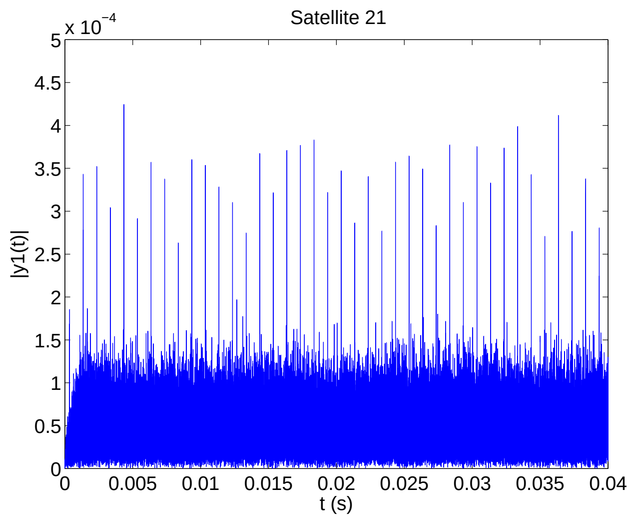

Figure 6: Signal from a satellite with a clear signal component

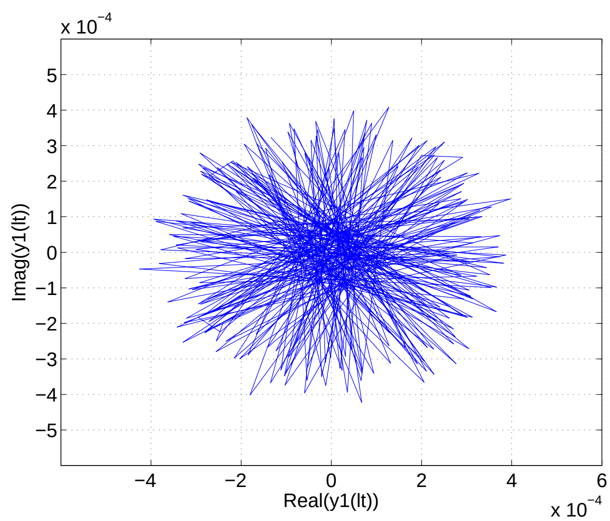

Figure 7: Phase of samples of the signal from a satellite 21

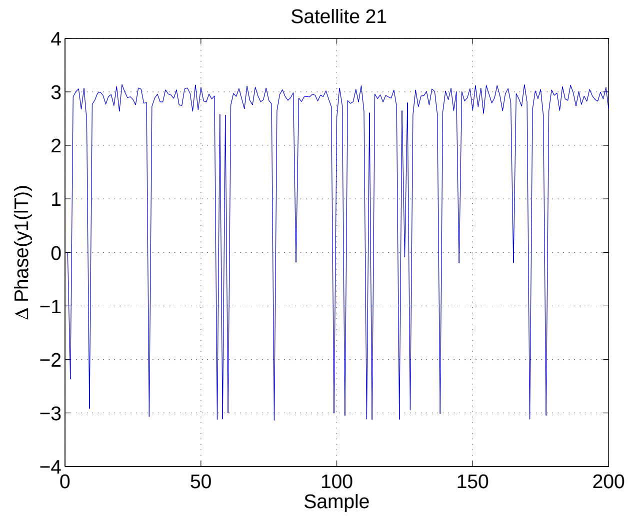

Figure 8: Change of phase of samples of the signal from a satellite 21

```
clear;
hold off;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                       %
%                 Simulation Parameters                 %
%                                                       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


N=2^20;
N2=N/2;
fmax=1.023e6
fs=2*fmax;          % Sampling Frequency
df=2*fmax/N
dt=1./(df.*N)
t=(1:N)*dt-dt;
f=(1:N)*df-df;
Tmax=N*dt
Nsc=2;                   % Number of Samples per chip
Nc=1023                  % Number of Chips per period
Tc=Nsc*dt;               % Chip Duration
Tb=Nc*Tc;                % Bit duration
rb=1/Tb;                 % Data Rate
Nsb=Nsc*Nc;              % Number of samples per bit
fc=0;                    % Center Frequency
Nb=floor(Tmax/(Tb))        % Number of bits simulated
P=1;

load gpsdata1
rf=fft(rt).*dt;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                       %
%                Generate Signals                       %
%                                                       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%==============================================%
%                                              %
%             GPS Gold Codes                   %
%          Generates different codes           %
%==============================================%
tap1=[2 3 4 5 1 2  1 2 3  2 3 5 6 7 8 9  1 2 3 4 5 6 1 4 5 6 7 8  1 2 3 4 ];
tap2=[6 7 8 9 9 10 8 9 10 3 4 6 7 8 9 10 4 5 6 7 8 9 3 6 7 8 9 10 6 7 8 9];

a1(1:10)=[1 1 1 1 1 1 1 1 1 1];   %Starting phases
a2(1:10)=[1 1 1 1 1 1 1 1 1 1];
for i=11:Nc a1(i)=rem(a1(i-10)+a1(i-3),2); end
for i=11:Nc a2(i)=rem(a2(i-10)+a2(i-9)+a2(i-8)+a2(i-6)+a2(i-3)+a2(i-2),2); end

for sat_num=1:32
    sat_num
    a3=rem(circshift(a2',tap1(sat_num)-10)'+circshift(a2',tap2(sat_num)-10)',2
    g1(sat_num,:)=rem(a1+a3,2);
end
g=(-1).^g1;

p=ones(1,Nsc);
ht=zeros(1,N);

for sat_num=1:32
sat_num;
at=zeros(1,N);
at(1:Nsc*Nc)=kron(g(sat_num,:),p);    % This is the spreading code for satelli
ht(1:Nsc*Nc)=fliplr(at(1:Nsc*Nc));    % Filter matched to satellite sat_num
hf=fft(ht).*dt;


%=======================================================%
%            Demodulate the signal                      %
%=======================================================%
y1f=rf.*hf;
y1t=ifft(y1f)/dt;
y2t=abs(y1t);
y2f=fft(y2t)*dt;
figure(1)
plot(t,y2t)
```

```
axis([0e-3 40e-3 0 5e-4])

% h2t=zeros(1,N);
% h2t((0:19)*Nc*Nsc+1)=1;
% h2f=fft(h2t).*dt;
% y3f=y2f.*h2f;
% y3t=ifft(y3f)/dt;
% figure(2)
% plot(t,abs(y3t))
% axis([0 0.04 0 10e-3])
% z(sat_num)=max(abs(y3t));
% pause(1)

%========================================================%
% Determine the appropriate sampling times
%========================================================%
[z2(sat_num),l2]=max(y2t);
k2=floor(l2/2046);            % Number of prior samples
st=(l2-k2*2046:2046:600000); % 600,000 is number of nonzero samples
y3t=y1t(st);                 % This is the samples of the signal

figure(3)
theta_pos=0;
theta_neg=0;
npos=0;
nneg=0;
%========================================================%
% This works for the two satellites of interest here      %
% but is probably not robust to work for all possible    %
% phases and Dopplers                                    %
%========================================================%
for mn=2:200
plot(y3t(1:mn))
axis([-6e-4 6e-4 -6e-4 6e-4])
grid on
%pause(.1)
theta(mn)=phase(y3t(mn)*conj(y3t(mn-1)));
if (theta(mn)>pi/2)
theta_pos=theta_pos+theta(mn);
npos=npos+1;
        elseif (theta(mn) < -pi/2)
                    theta_pos=theta_pos+theta(mn)+2*pi;
                    npos=npos+1;
else theta_neg=theta_neg+theta(mn);
nneg=nneg+1;
end
end
```

```
figure(4)
plot(theta)
grid on
theta_avep=theta_pos/npos;
theta_aven=theta_neg/nneg;
y4t=y3t.*exp(-j*theta_avep*(1:length(y3t)));
    fdoppler(sat_num)=theta_avep/(2*pi*1e-3)
end
[z2',fdoppler']
```