Optics and Radar based Observations

Assignment 2

Pulse Modulation Techniques

Sergio Martin del Campo Barraza
Diwei Zhang
May 13th, 2011

SpaceMaster

1. **Introduction to the Problem**

A Mesosphere-Stratosphere-Troposphere (MST) radar is an instrument used to measure the wind and some other atmospheric parameters in altitudes no bigger than 100 Km. This measurement is possible by the turbulence in the neutral atmosphere that causes fluctuations in the refractive index, these fluctuations can be enhanced by a strong vertical gradient in electron density. Therefore, the variations in the refractive index reflect the variations in the atmosphere parameters. The parameters upon the refractive index depend are humidity, temperature, pressure, electron density and radar operating frequency. [6][3]

This assignment provides us with data obtained from ESRAD MST radar. This radar operates at 52 MHz with a repetition frequency from 100 Hz to 16 kHz which provides height resolutions between 150 and 3000 m. This data consists of Universal Time, Altitude, Signal amplitude, signal-to-noise ratio (SNR), zonal wind, meridional wind and vertical wind. [3]

In order to better understand how the radar operates and data is processed, we need to understand the correlation and ambiguity functions and how is the output for different pulse modulation techniques like pulse train, long pulse, short pulse, barker code, complementary and frequency coding using LFM.

The following part of the task is to see how the height resolution affects the obtained data from the data. We will compare data with 150 and 1200 m height resolution. This comparison will show the differences between each set of data. This is important because each set has a different pulse length and conflicting requirements might come regarding the best length and the idea is to obtain the more useful data. These conflicting requirements could come because the atmosphere is constantly changing and the ideal would be to keep a short pulse but at the same time a strong long pulse is needed in order to be detected above the natural noise. [3]

The last part of the assignment consists on reviewing a signal-processing technique called pulse coding which allows keeping the strength of a pulse at the same time that the height resolution is reduced. In order to review this, we will review three data sets, make a comparison and calculate the horizontal wind having as inputs the zonal wind, meridional wind and vertical wind.

2. Part 1A – Auto Correlation and Ambiguity Functions

The auto correlation function is a measurement of the degree of similarity of a signal with itself as a function of the separation between both. This function is useful to find patterns that might be hidden under the noise. This function is useful because even if you have infinite or really long time signals, you can take a portion of it and treated as a short time function. [2]

The ambiguity function is the representation of a function of time delay and Doppler frequency of an altered pulse by a Doppler shift of a given signal correlated with its auto correlation function in order to detect its presence. The idea is to give an indication of how useful is a signal as part of the desired application. [1].

The objective of the task is to review the auto correlation and ambiguity functions for different pulse modulation techniques. The reviewed techniques include a pulse train, a long pulse, a 1-bit short pulse, phase coding with Barker 11, phase coding with complementary code and frequency coding with Linear Frequency Modulated (LFM) code.

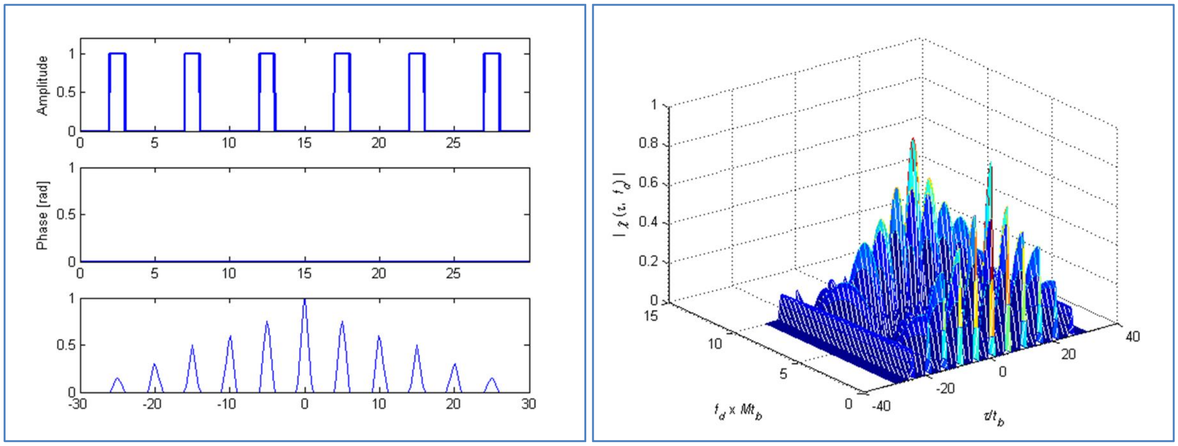

Figure 1 – Auto correlation and ambiguity functions for a pulse train

The response of the auto correlation and ambiguity functions to a train pulse demonstrates that the maximum value occurs at the origin with zero Doppler shift and zero delay. It can also be seen the existence of many ambiguities on the Doppler shift and delay planes which is in accordance with a pulse train because of the oscillations. Now, since the ideal ambiguity diagram consists of a single spike of infinitesimal thickness and if we do not receive a radar echo in between the pulses of the train pulse then the effective diagram is reduced to a single spike similar to the ideal one therefore the train pulse will become a useful pulse modulation technique. [4]

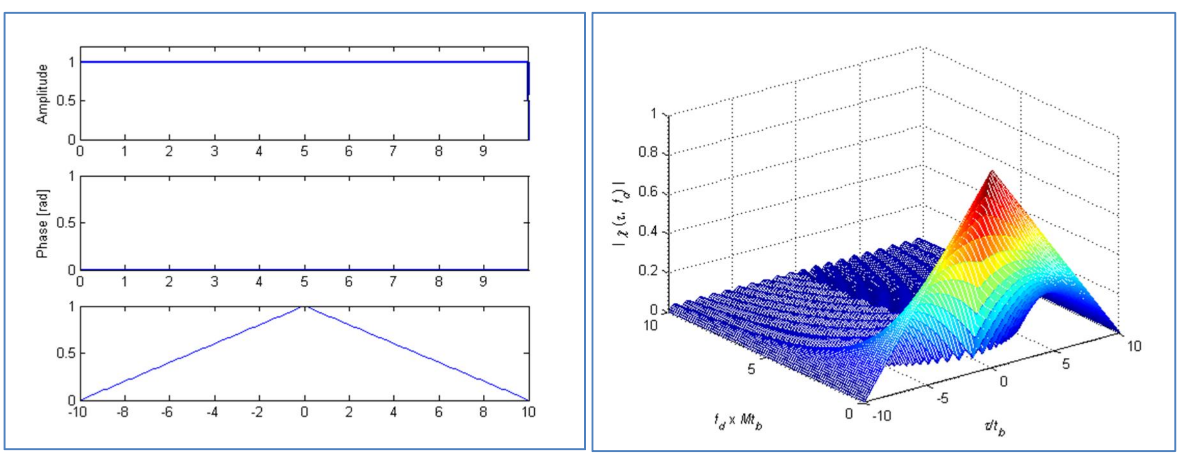

Figure 2 – Auto correlation and ambiguity functions for a long pulse

As it can be from figure 2, a long pulse will show a good response in the Doppler shift in frequency with a peak in zero as one of the properties of the ambiguity function. However, concerning to the response in the time delay, this will not be as good as in the Doppler shift since it does not show any responses to time delay meaning that there is not delay on the shift. Therefore a long pulse will give a good accuracy in the Doppler frequency measurement and a poor time delay accuracy. [4]

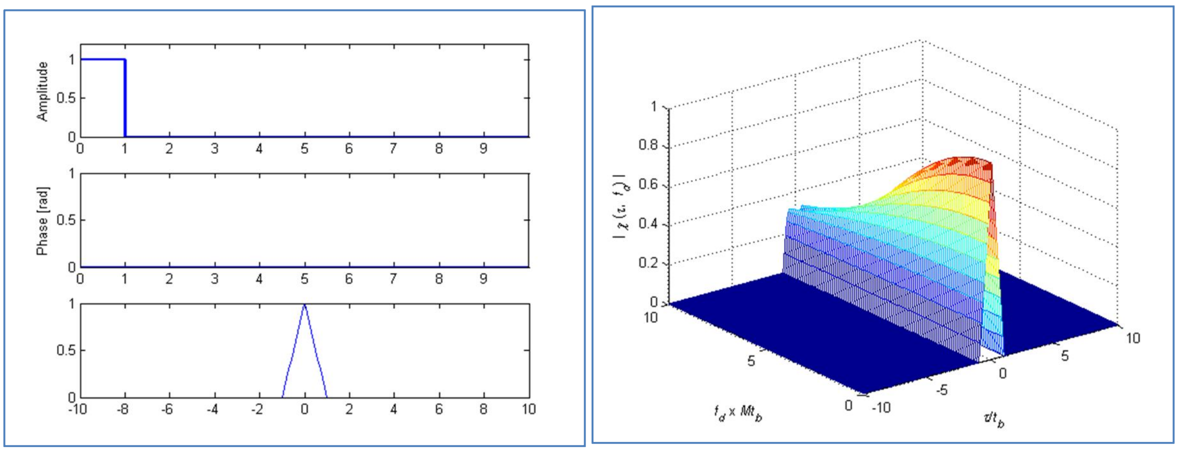

Figure 3 – Auto correlation and ambiguity functions for a short train (1 bit)

The response to a short pulse can be seen on figure 3. Having a short pulse presents an opposite situation to the long pulse. The short will give an accurate response in the time delay and a poor accuracy in the Doppler shift frequency. This means that a short pulse modulation technique is only useful when the actual signal does not carry a Doppler shift since the response is centred entirely on zero. [4]

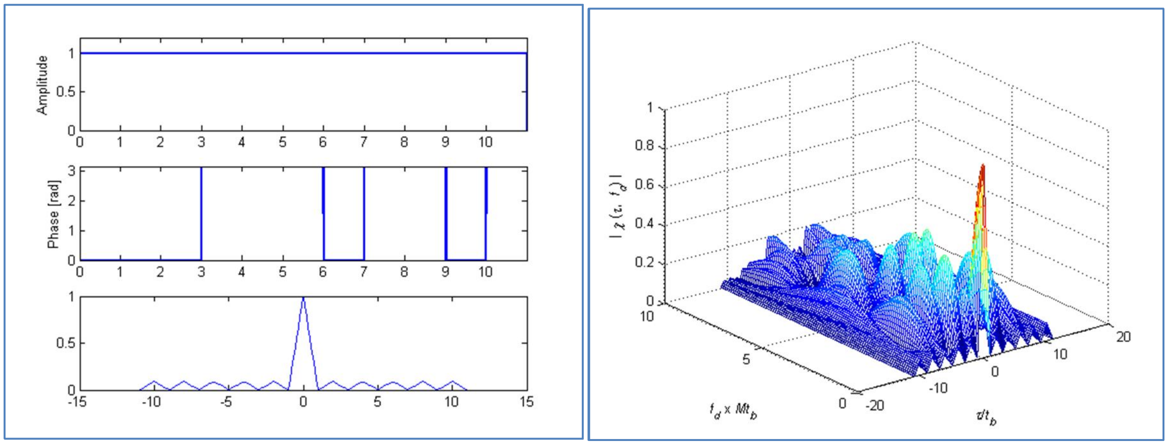

Figure 4 – Auto correlation and ambiguity functions for a Barker (11) phase coding

A Barker phase coding shows good Doppler shift and time delay accuracy. In the Doppler shift plane it shows the highest value centred on zero at the same time it shows a good distribution along the Doppler shift plane. The good distribution continues on the time delay where ambiguities are seen along the entire time delay plane. This way Barker phase coding becomes rather useful because it gives the lowest time levels that are not zero. [5]

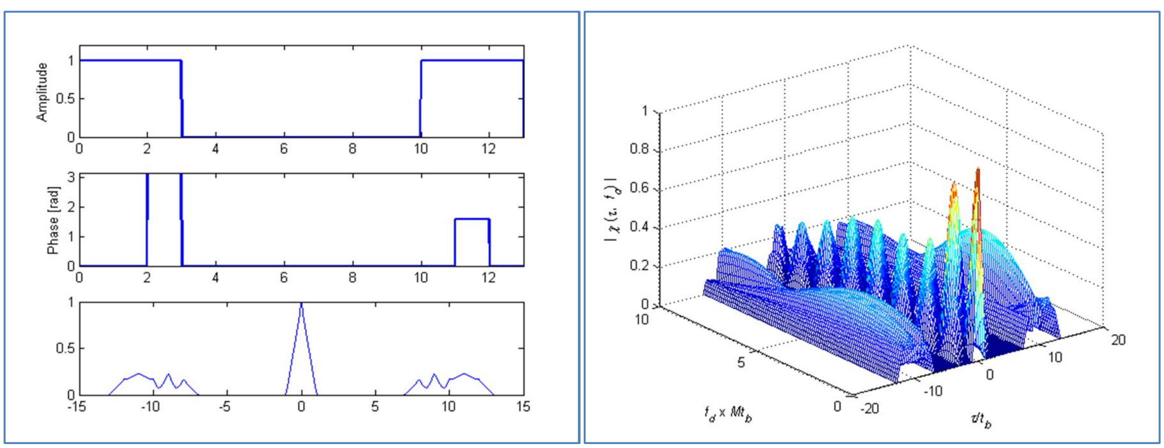

Figure 5 – Auto correlation and ambiguity functions for complementary phase coding

The complementary phase coding intends to create two sequences with the higher value at the origin and lateral sides at zero since these the two sequences would be equal but with different sign therefore the sum would be zero. However since the two sequences are separated in delay time and Doppler shit frequency the zero is difficult to achieve and the cancellation is rather difficult, otherwise the distribution on the time delay would have been accurate and would have provided a window for the Doppler shift. [5]

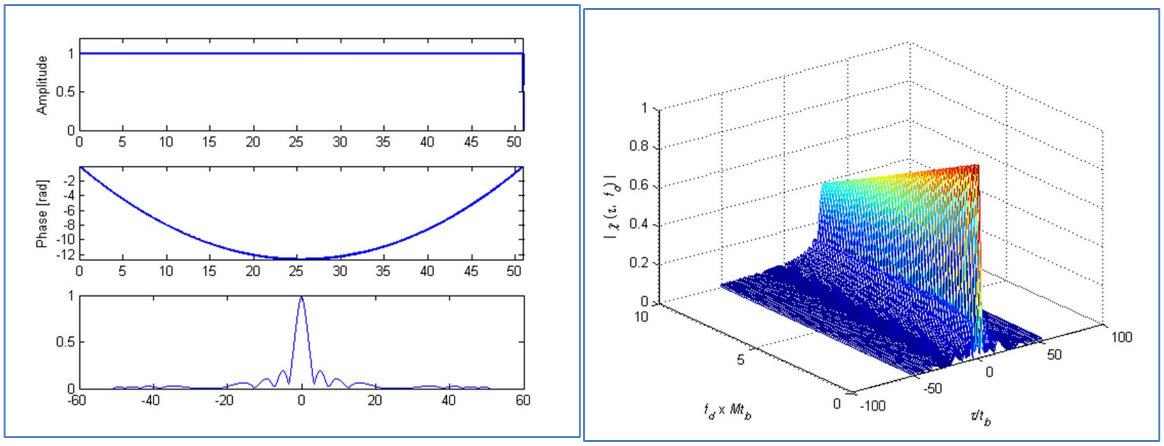

Figure 6 – Auto correlation and ambiguity functions for frequency coding with LFM

The last pulse modulation technique is the frequency coding with LFM. This technique gives a ridge ambiguity diagram which is dependent on the bandwidth and the pulse width. This gives the characteristic that the time delay accuracy depends on the bandwidth and the Doppler shift frequency accuracy depends on the time delay and since both are independent of each other their accuracies are independent. [4]

3. Part 2A – Height Resolution

The height resolution of a radar signal is limited by the length of the pulse. Usually there are two conflicting requirements when defining the length of the pulse, the first is that because the atmospheric conditions are changing constantly the pulse should be as short as possible in order to better detect these changes at different altitudes. At the same time, in order to get a strong signal the pulse sent should be as long as possible; therefore a middle point between both requirements is needed.

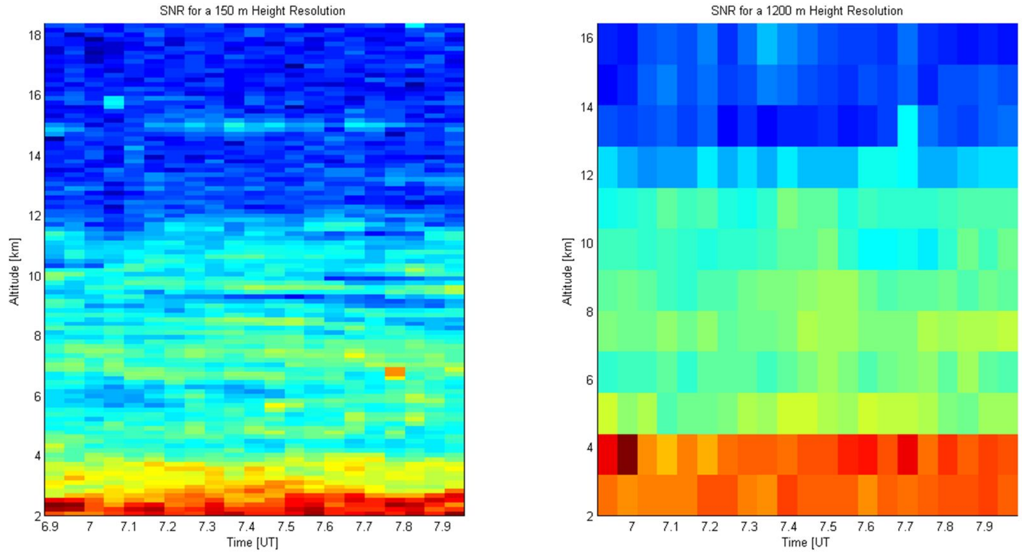

Figure 7 – SNR data for 150 and 1200 m Height Resolution

Figure 7 shows the Signal-to-Noise Ratio for two different height resolutions. Both figures present pros and cons. The figure with a 150 m height resolution (left) provides more information at different altitudes giving a better representation of the atmospheric conditions on smaller distances however the average power of the entire data is small; this can be seen by the great amount of areas on blue which means a low SNR. The opposite occurs with the figure with 1200 m height resolution (right). The average power for the entire plot is greater than in the previous plot, the area covered by red/orange is larger, however at the same time the gain in power is affected by the lost on resolution at the different altitudes. Therefore it becomes more difficult to learn the environmental conditions on smaller distances. The best resolution is the one that gives you the more information and accurate data based on the desired requirements. In certain situations, better resolution might be required even if it means getting smaller signals but if it is a strong signal that is required, even if a great resolution is not achieved, the other situation might be best.

4. **Part 2B – Pulse coding**

Once the height resolution of the data has been selected, the next step requires selecting the best signal-processing technique. This will allow reducing the height resolution at the same time that the strength of the data is retained. The options to perform this are usually Barker coding or complementary coding. The characteristics of each technique were already discussed on part 1A.

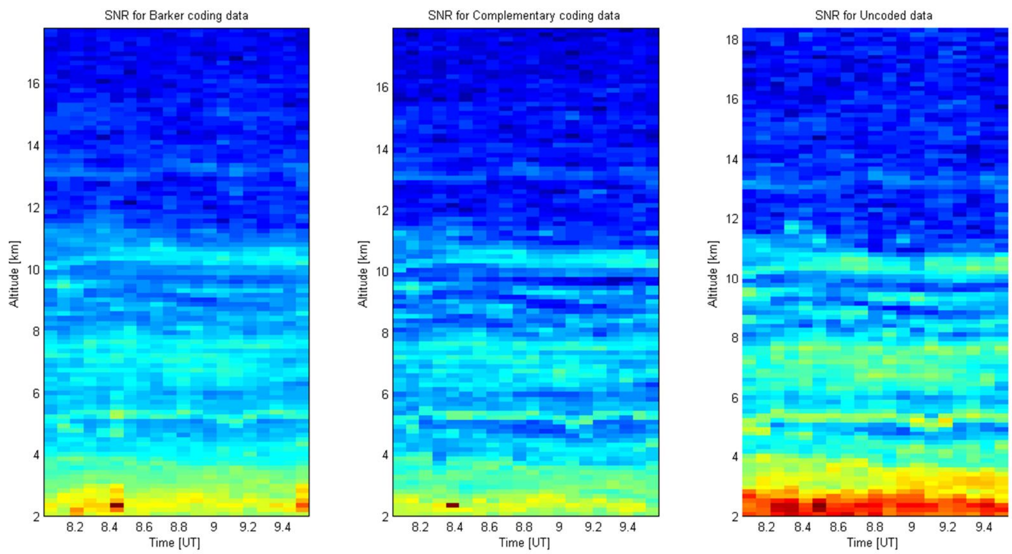

Figure 8 – SNR data for different pulse coding techniques

The above figure shows the same data with the two different signal-processing techniques on it. The plot at the right is the raw uncoded data which can be used as reference. The plot to the left was plotted using Barker coding and the plot in the middle used complementary coding. The original uncoded data shows how at the lower part of the plot there is a high SNR, then these values decrease, then increase again in the middle part and finally decrease at the top of the plot. Using complementary coding (middle plot) it looks like reducing the overall value of the SNR on the plot at the same time that the up and down along the vertical axis is maintained, this causes to have a larger area on blue on in the lower middle part. The Barker coding seems to try to reduce the SNR value on a way that will affect mainly to the ups and downs along the vertical axis causing to have a more gradual change in the values of the SNR and a reduction in the number of dark blue areas in the lower middle part but with an increase in the light blue areas. Given that in both cases the height resolution was the same the pulse technique affects mainly the SNR. The selection of the most adequate method depends, at the end, on the particular needs of the assignment. However, this test data seems to indicate that Barker coding might be a better technique since it does seem to affect the entire plot on the same degree and helps to keep the smooth changes along the plot.

The last part of the task required to estimate the values and direction of the horizontal winds. In order to perform this we require the zonal and meridional wind speed values. The zonal wind is the one along the latitude circle and the meridian wind is along the meridian. The horizontal wind is the resultant of these two values. [7]

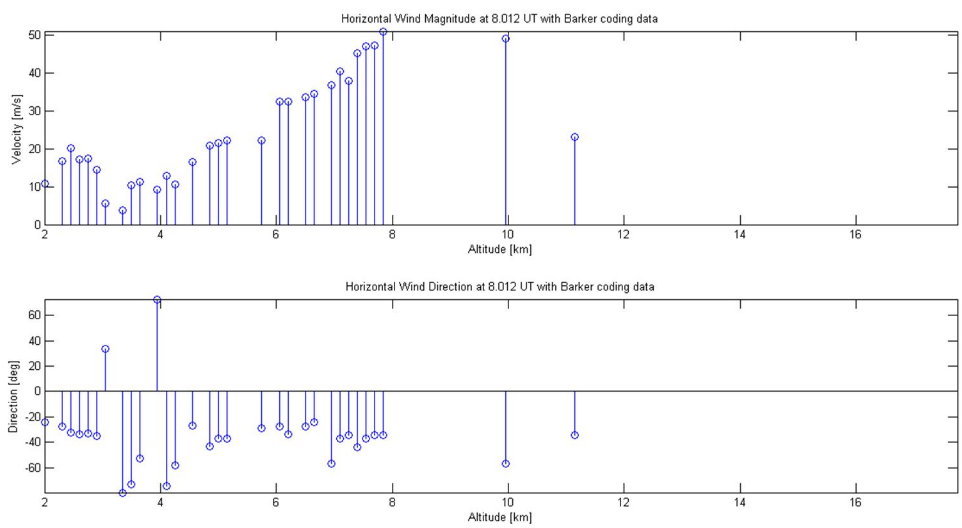

Figure 9 – Value and Direction of Horizontal WInd

Since the wind values for the entire range of altitudes were not available, only the horizontal wind value for the available data was estimated. It was defined that an angle of zero degrees corresponds to the East direction and any positive angle value would mean a north wind direction and a negative value would mean a south direction. It can be notice, up to the point where most of the data was available, that the higher it is the altitude the faster the wind velocity it becomes. In addition, at most of the altitudes the wind seems to be flowing on a south-eastern direction however, not because this is happening means that the entire altitude range would fly on the same direction.

5. References

[1] Ambiguity Function, Wikipedia,
URL http://en.wikipedia.org/wiki/Ambiguity_function
Last updated: May 3rd, 2011

[2] Autocorrelation, Wikipedia,
URL http://en.wikipedia.org/wiki/Autocorrelation_function
Last updated: May 11th, 2011

[3] Barabash, Victoria, *Assignment 2 Pulse modulation technique,* Optics and Radar based Observations, 2011

[4] Merrill.Skolnik, *Introduction to Radar Systems,* 3rd ed. McGraw-Hill Education,2001

[5] Merrill.Skolnik, *Radar Handbook,* 3rd ed. McGraw-Hill Education,2009

[6] MST Radar, Glossary of Meteorology,
URL http://amsglossary.allenpress.com/glossary/search?id=mst-radar1
Last accesed: May 10th, 2011

[7] Zonal and meridional, Wikipedia
URL http://en.wikipedia.org/wiki/Zonal_and_meridional,
Last updated: February 17th, 2011

Implemented MatLab Codes

```
function part2A

%Code to process radar data for Height Resolution

%Procedure for 150 m Height Resolution
test1data = importdata('TXT_20071011_test1.FCA');

%Creating time and altitude vectors and SNR matrix
time1=test1data(1:110:length(test1data),1);
altitude1=test1data(1:110,2);

for lapse1 =1:22;
    t1=(110*(lapse1-1))+1;
    t2=(110*(lapse1));
    SNRp1=test1data(t1:t2,4);
    SNR1(:,lapse1)=SNRp1;

end;

%Plotting test1 data
subplot(1,2,1)
pcolor(time1,altitude1,SNR1)
shading flat
colormap jet
title('SNR for a 150 m Height Resolution')
ylabel('Altitude [km]')
xlabel('Time [UT]')

%Procedure for 12000 m Height Resolution
test2data = importdata('TXT_20071011_test2.FCA');

%Creating time and altitude vectors and SNR matrix
time=test2data(1:13:length(test2data),1);
altitude=test2data(1:13,2);

for lapse =1:22;
    t1=(13*(lapse-1))+1;
    t2=(13*(lapse));
    SNRp=test2data(t1:t2,4);
    SNR(:,lapse)=SNRp;

end;

%Plotting test2 data
subplot(1,2,2)
pcolor(time,altitude,SNR)
shading flat
colormap jet
title('SNR for a 1200 m Height Resolution')
ylabel('Altitude [km]')
xlabel('Time [UT')
```

```
function part2B

%Assigment 2
%Sergio Martin del Campo Barraza
%Diwei Zhang
%
%Code to process radar data for different coding techniques


%Procedure for Barker coding data
test3data = importdata('TXT_20071011_test3.FCA');

%Creating time and altitude vectors and SNR matrix
time3=test3data(1:106:length(test3data),1);
altitude3=test3data(1:106,2);

for lapse3 =1:21;
    t1=(106*(lapse3-1))+1;
    t2=(106*(lapse3));
    SNRp3=test3data(t1:t2,4);
    SNR3(:,lapse3)=SNRp3;

end;

%Plotting test3 data
subplot(1,3,1)
pcolor(time3,altitude3,SNR3)
shading flat
colormap jet
title('SNR for Barker coding data')
ylabel('Altitude [km]')
xlabel('Time [UT]')


%Procedure for Complementary coding data
test4data = importdata('TXT_20071011_test4.FCA');

%Creating time and altitude vectors and SNR matrix
time4=test4data(1:107:length(test4data),1);
altitude4=test4data(1:107,2);

for lapse4 =1:21;
    t1=(107*(lapse4-1))+1;
    t2=(107*(lapse4));
    SNRp4=test4data(t1:t2,4);
    SNR4(:,lapse4)=SNRp4;

end;

%Plotting test4 data
subplot(1,3,2)
pcolor(time4,altitude4,SNR4)
shading flat
colormap jet
```

```
title('SNR for Complementary coding data')
ylabel('Altitude [km]')
xlabel('Time [UT]')


%Procedure for uncoded data
test5data = importdata('TXT_20071011_test5.FCA');

%Creating time and altitude vectors and SNR matrix
time5=test5data(1:110:length(test5data),1);
altitude5=test5data(1:110,2);

for lapse5 =1:20;
    t1=(110*(lapse5-1))+1;
    t2=(110*(lapse5));
    SNRp5=test5data(t1:t2,4);
    SNR5(:,lapse5)=SNRp5;

end;

%Plotting test5 data
subplot(1,3,3)
pcolor(time5,altitude5,SNR5)
shading flat
colormap jet
title('SNR for Uncoded data')
ylabel('Altitude [km]')
xlabel('Time [UT]')


%Horizontal Wind Magnitude
zonalwind3x=test3data(1:106,5);
meridionalwind3y=test3data(1:106,6);
horizontalwind3=zeros(106,1);

for all = 1:106;
    horizontalwind3(all,1)=sqrt( (zonalwind3x(all,1))^2 +
(meridionalwind3y(all,1))^2 );
end;

figure
subplot(2,1,1)
stem(altitude3,horizontalwind3(:,1))
axis tight
title('Horizontal Wind Magnitude at 8.012 UT with Barker coding data')
ylabel('Velocity [m/s]')
xlabel('Altitude [km]')

%Horizontal Wind Direction
horizontalwind3rad=zeros(106,1);
horizontalwind3deg=zeros(106,1);

for all = 1:106;
    horizontalwind3rad(all,1)=atan(
(meridionalwind3y(all,1))/(zonalwind3x(all,1)) );
```

```
    horizontalwind3deg(all,1)=(horizontalwind3rad(all,1)*180)/pi;
end;

subplot(2,1,2)
stem(altitude3,horizontalwind3deg(:,1))
axis tight
title('Horizontal Wind Direction at 8.012 UT with Barker coding data')
ylabel('Direction [deg]')
xlabel('Altitude [km]')
```

Note:

The code for Part 1A is not included since it was the same for the entire group and it was generated by Dr. A. Enmark.

Confirmation of Participation

The purpose of this document is to confirm our participation in the realization of this assignment. The members of this team participated on the investigation of the required information to solve the assignment, generated their code to perform the calculation and discussed the results.

____

Diwei Zhang

____

Sergio Martin del Campo Barraza