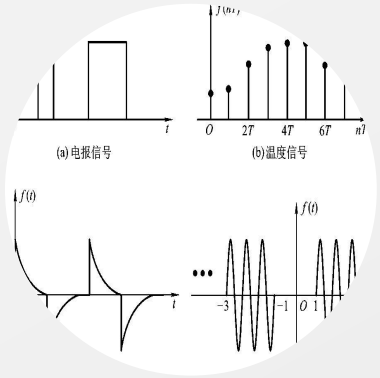
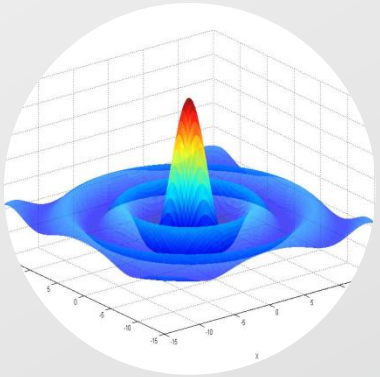
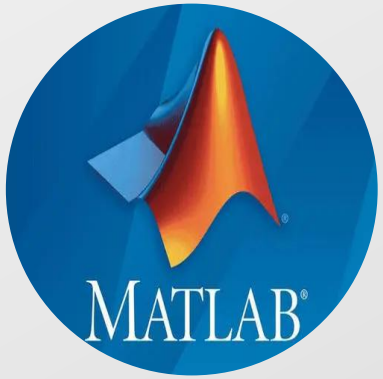
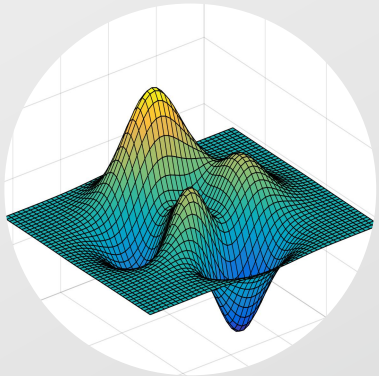
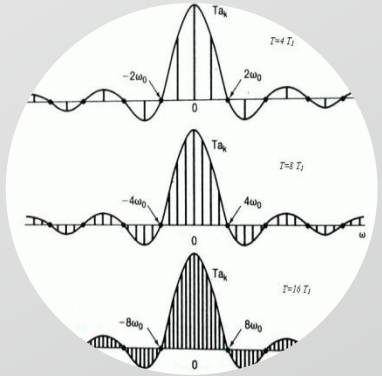






Project2：Motion detection via communication signals

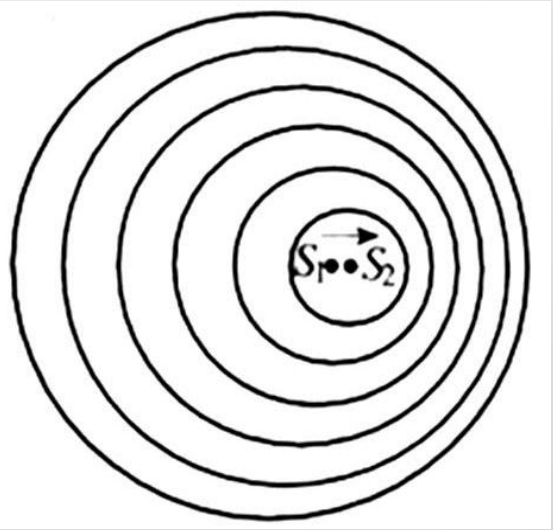


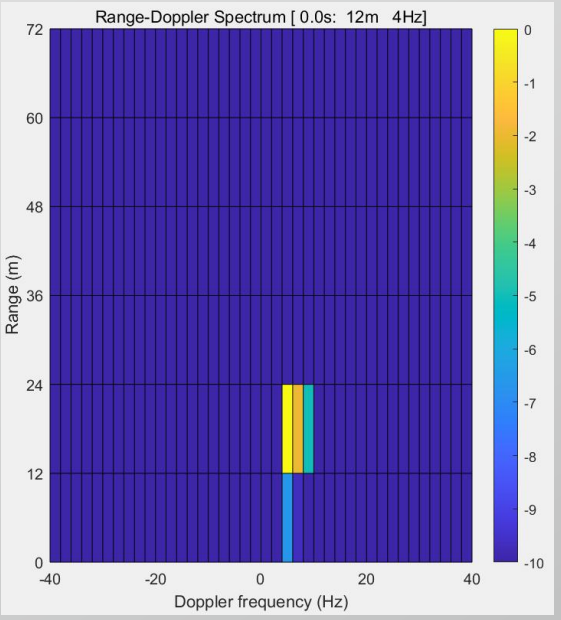


主讲老师：王小静
办公地点：一教131

Overview

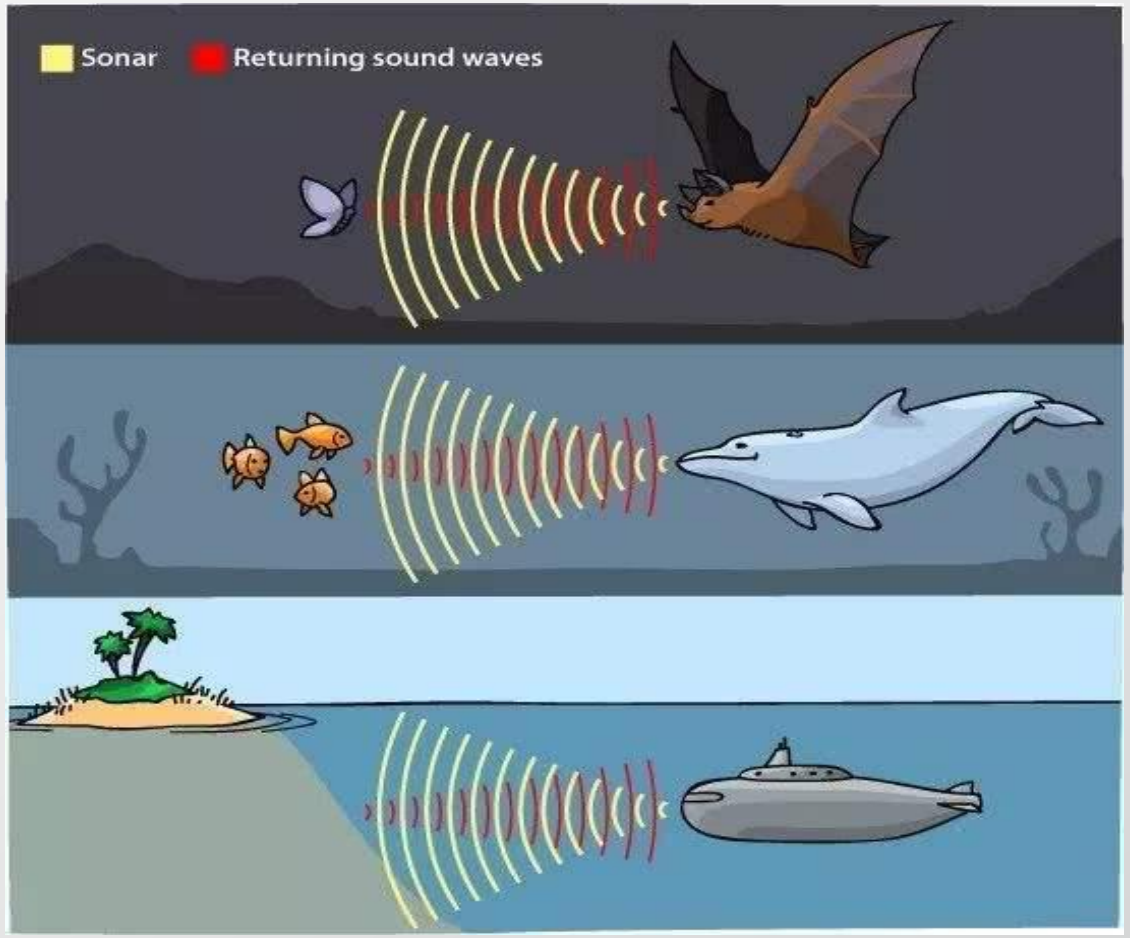
- **Part I： Background**
  - Target Localization by Rador
  - Multipath propagation
  - Doppler shift
- **Part II： Passive Rador Introduction**
  - The basic principle of Passive Rador
  - Cross-Correlation(ambiguity function)
  - Target Range/Doppler Tracking
- **Part III： Project Tasks**
  - Measurement Environment

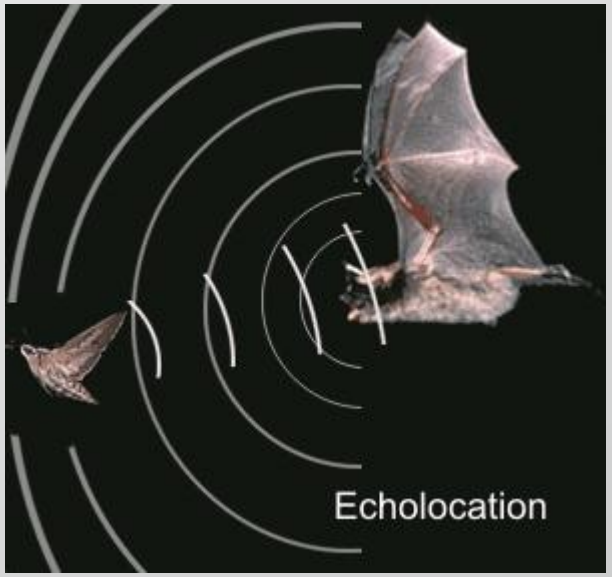




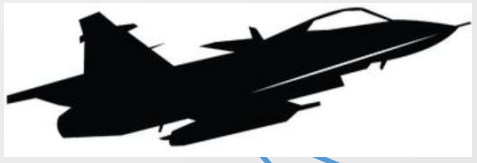
Part I: Backgound

Target Localization

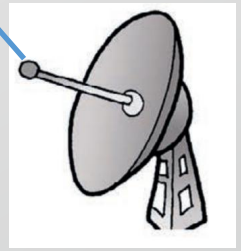




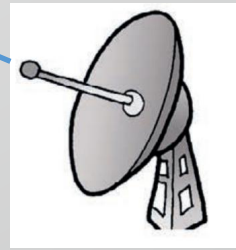
Active Radar



Target

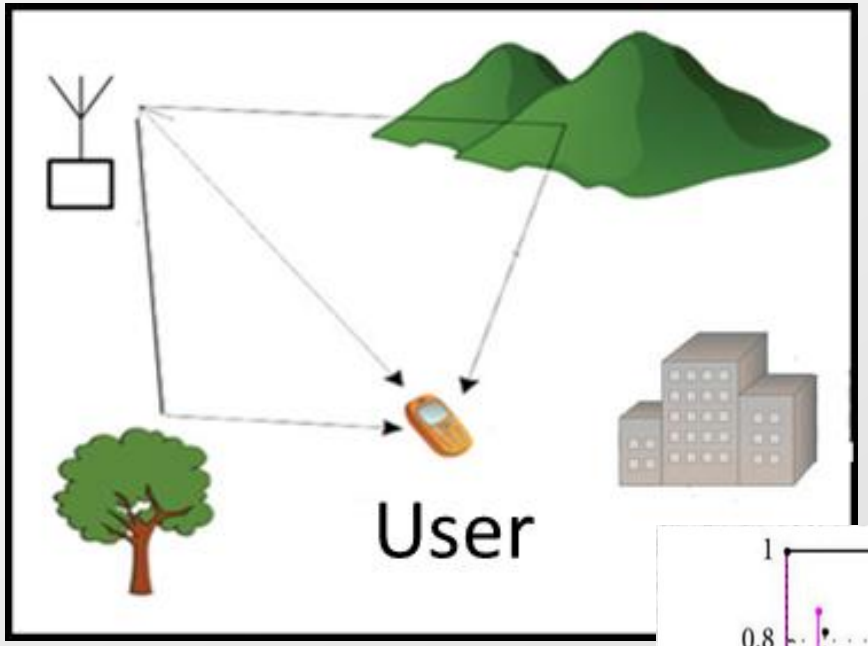


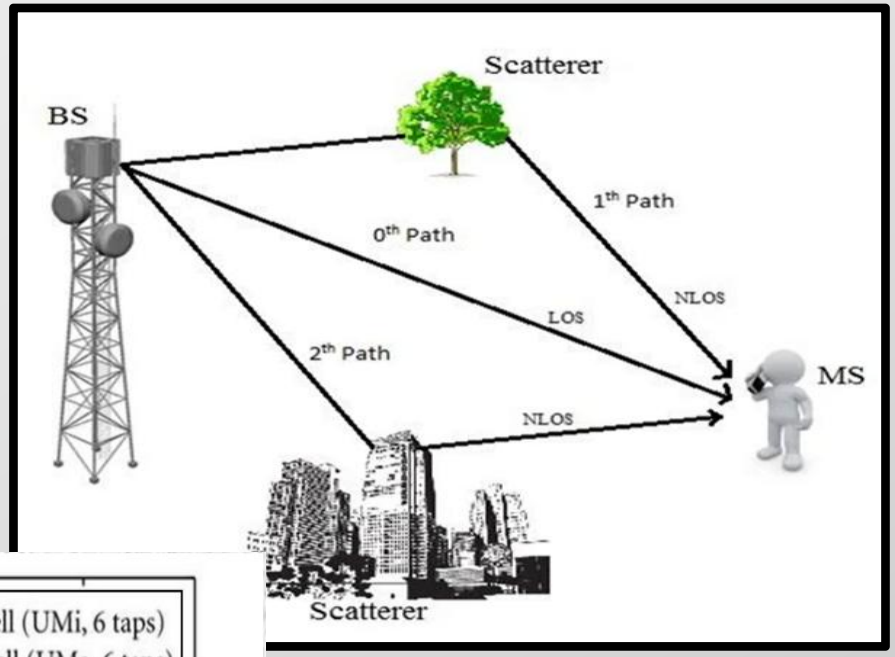
Transmitter Radar

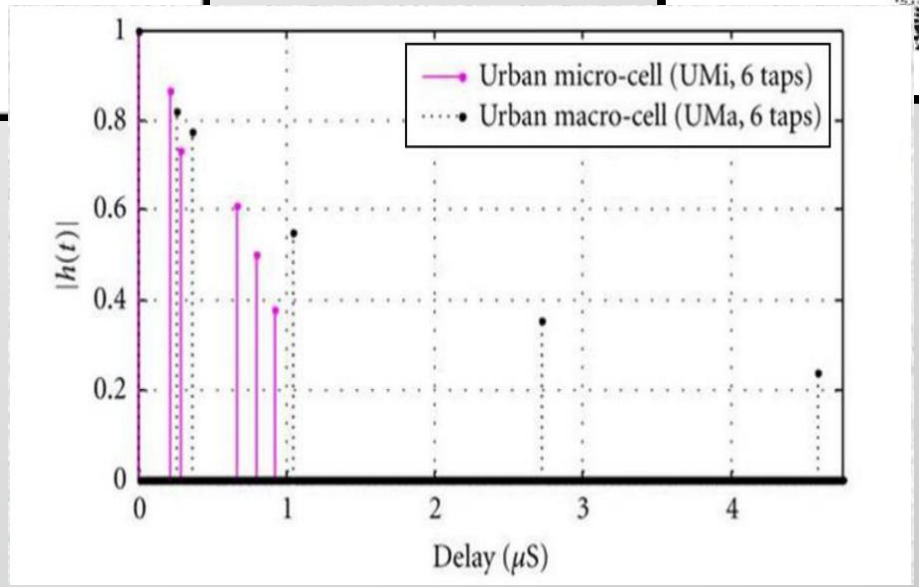


Receiver Radar

Multi-path propagation



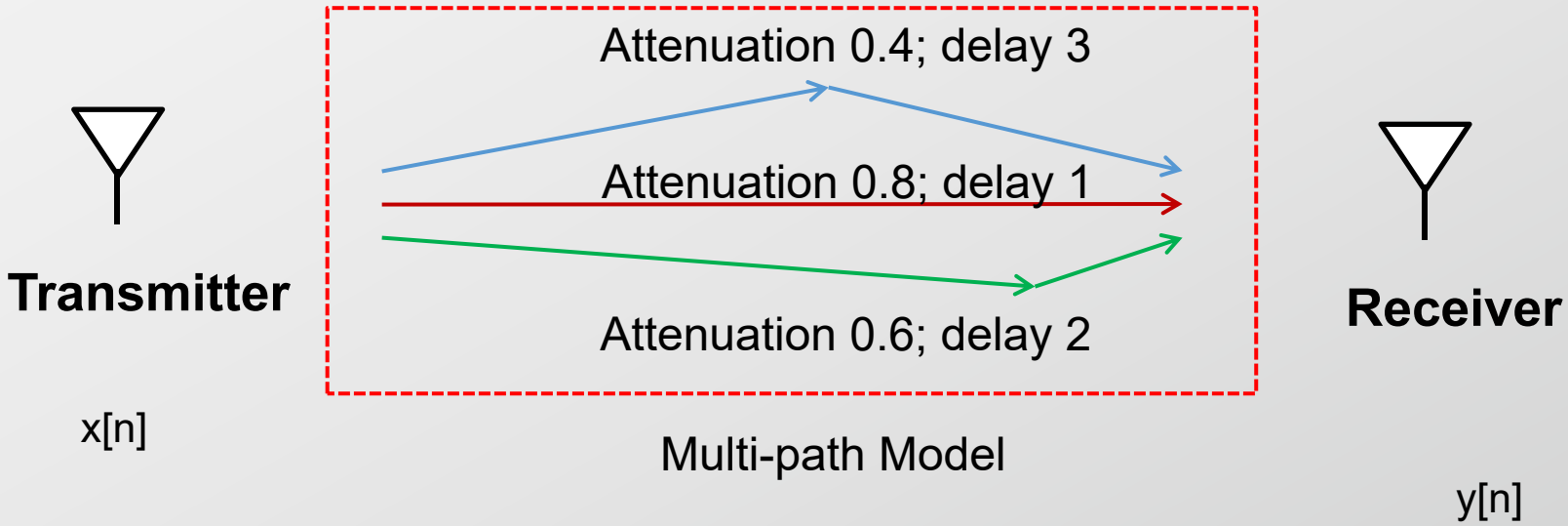


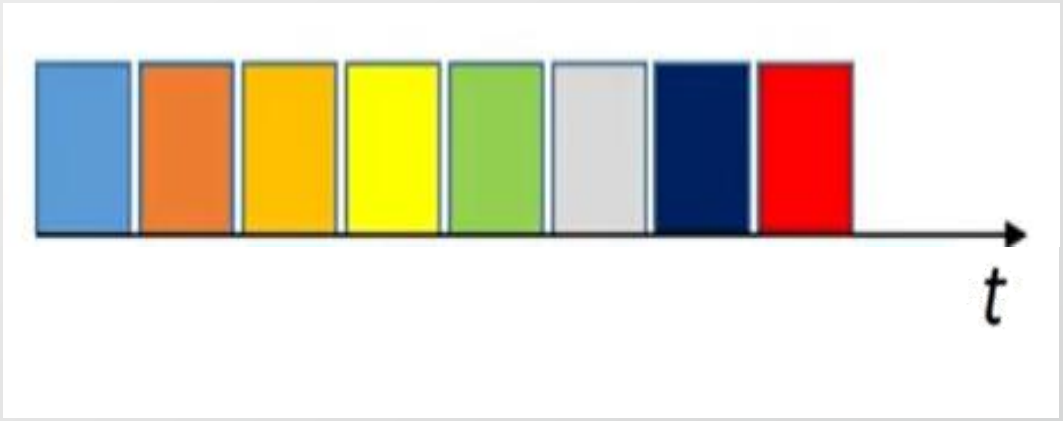


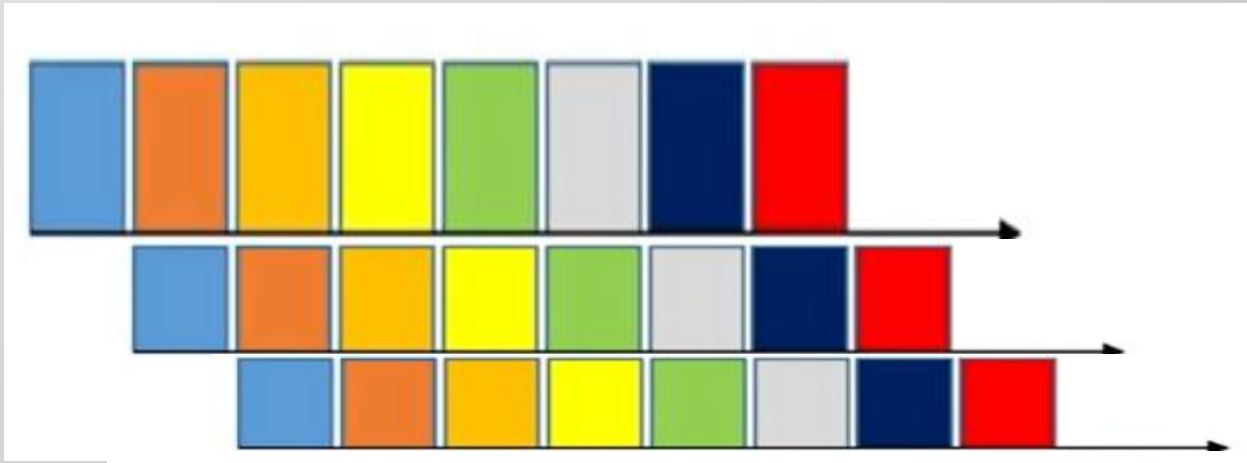
Multi-path Delay Spread

Multi-path Model:

$$h[n] = 0.8\delta[n-1] + 0.6\delta[n-2] + 0.4\delta[n-3]$$







Doppler Shift

The difference between the transmitted and received frequencies caused by object movement is called Doppler shift.

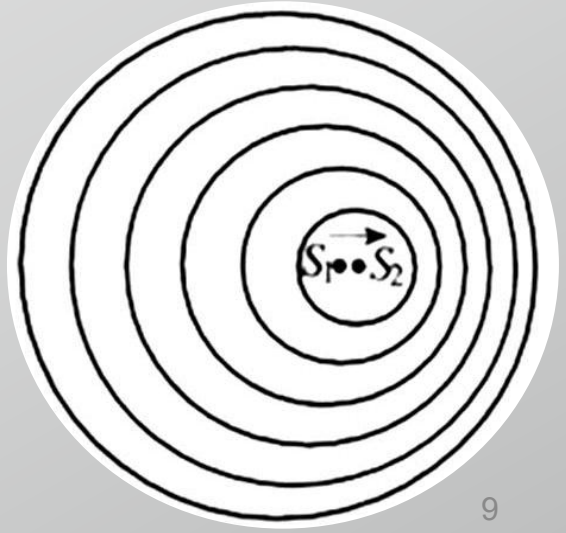
$$\Delta f = f' - f$$

f' : the frequency that's received

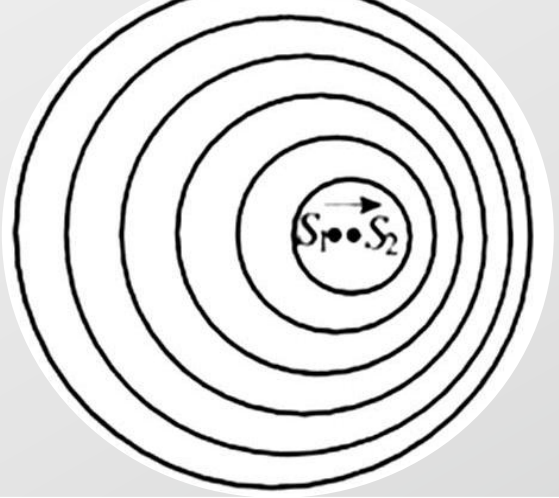
f : the frequency that's transmitted

Closer: $\Delta f > 0$;

Farther: $\Delta f < 0$。



$$f' = \left(\frac{v \pm v_o}{v \mp v_s} \right) f$$



f' : the frequency that's received;

f : the original frequency that's transmitted;

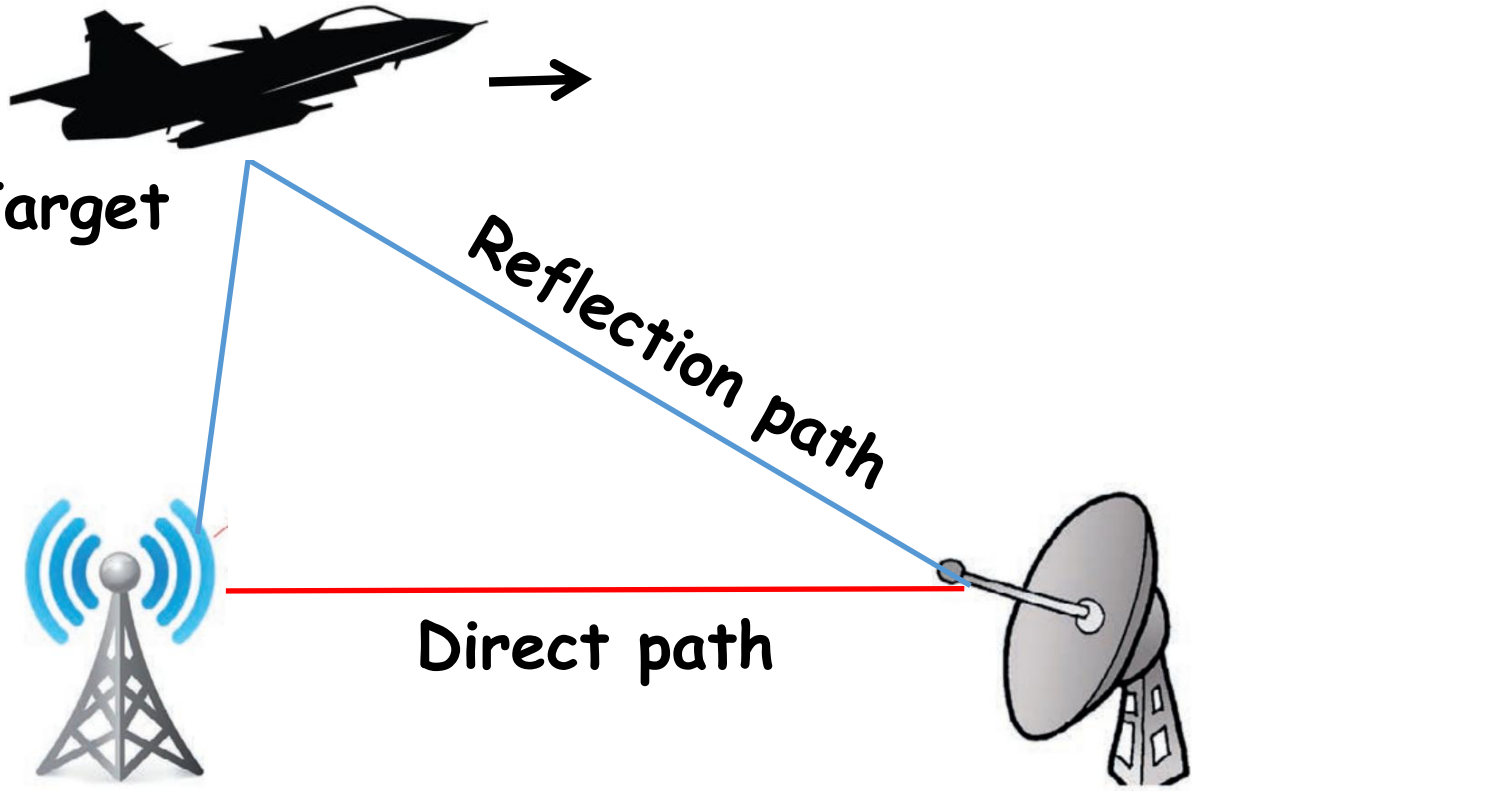
v : the travel speed of waves in the medium;

v_o : the moving speed of the receiver relative to the medium. If it is closer to the transmmiter, the front operation symbol is + sign, otherwise it is − sign;.

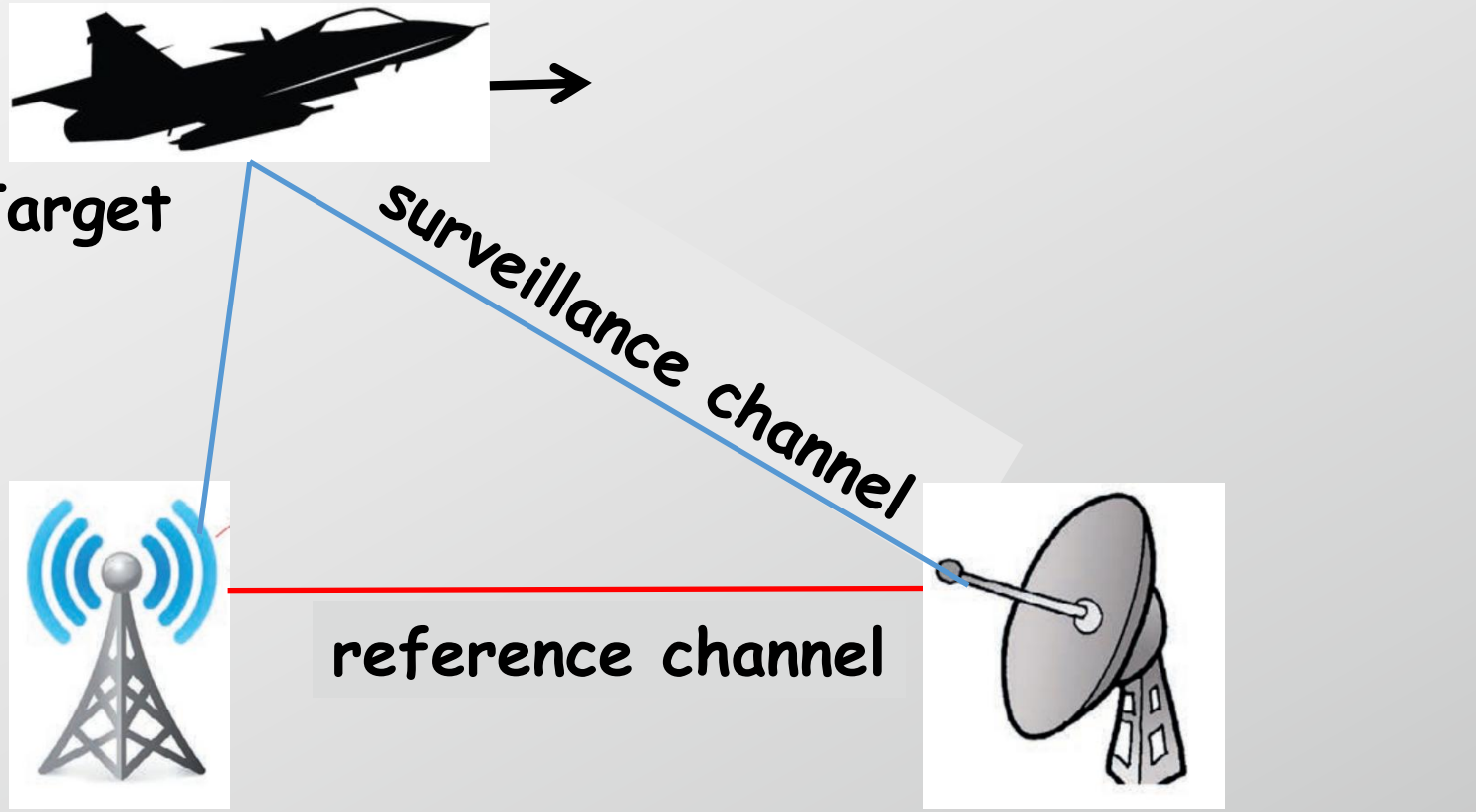
v_s : the moving speed of the transmitter relative to the medium. If it is closer to the receiver, the front operation symbol is − sign, otherwise it is + sign.

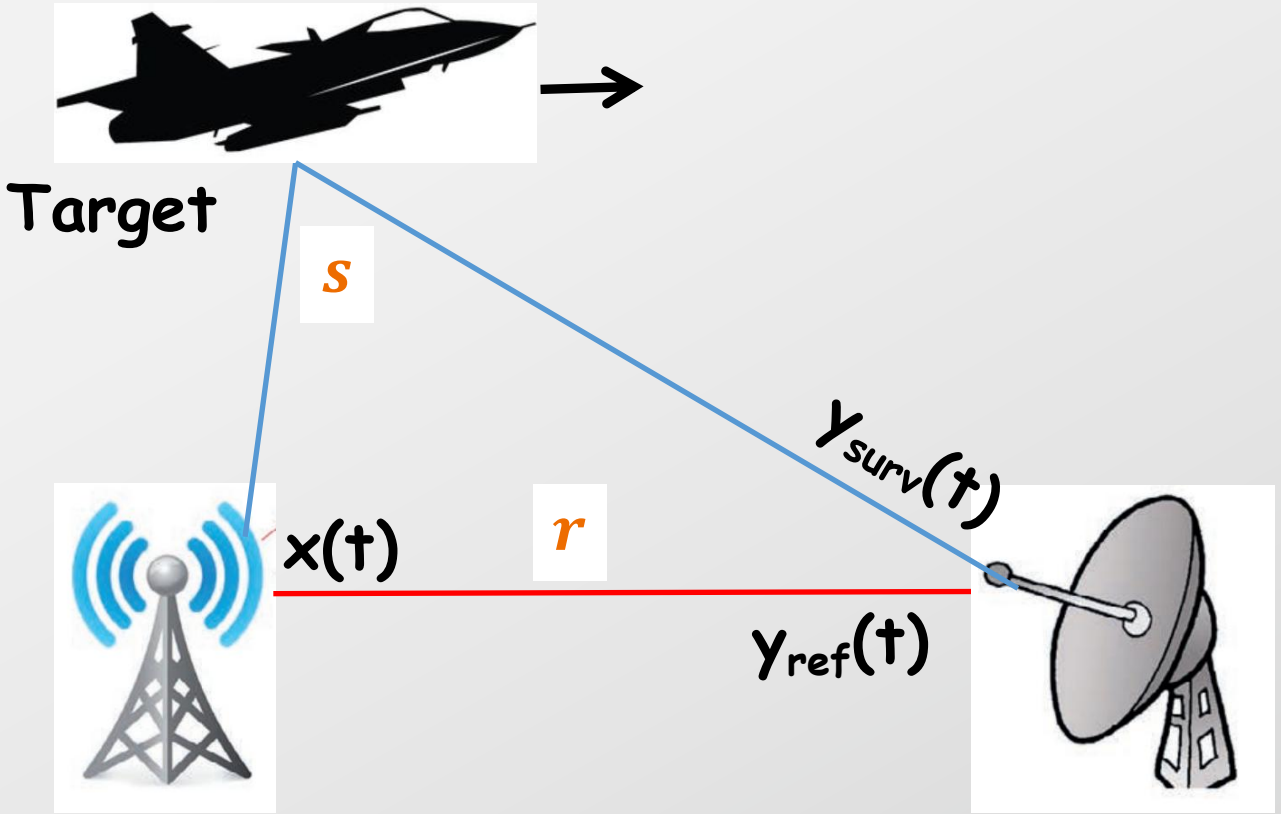
Part II: Passive Rador Introduction

Passive Radar



The basic principle of Passive Rador





Suppose the transmitted signal is x(t)

- The reference signal is the transmitted signal after time delay and attenuation:

$$y_{ref}(t) = \alpha x(t - \tau_r)$$

- The survillance signal is the transmitted signal after attenuation, time delay and Doppler frequency offset:

$$y_{surv}(t) = \beta x(t - \tau_s) e^{j2\pi ft}$$

$$\tau_r = \frac{r}{c} \qquad \tau_s = \frac{s}{c} \qquad f = \frac{v f_c}{c}, \; where \; v = \frac{ds}{dt}$$

Cross-Correlation(ambiguity function)

$$Cor(\tau, f_D) = \int_t^{t+T} y_{surv}(t) y_{ref}^*(t-\tau)\, e^{-j2\pi f_D t} dt$$

where $y_{surv}(t)$ is the complex envelope of the signal received in the surveillance channel, $y_{ref}(t)$ is a (cleaned) replica of the transmitted signal, τ is the potential TDOA of the target echo signal, and f_D is the potential corresponding bistatic Doppler. (TDOA:the Time Difference of Arrival between the reference signal and the surveillance echo.)

The cross-correlation between the reference signal and the surveillance signal， also referred to as Range-Doppler correlation.

Target Range/Doppler Tracking

$$Cor(\tau, f_D) = \int_t^{t+T} y_{surv}(t) y_{ref}^*(t-\tau)\, e^{-j2\pi f_D t} dt$$

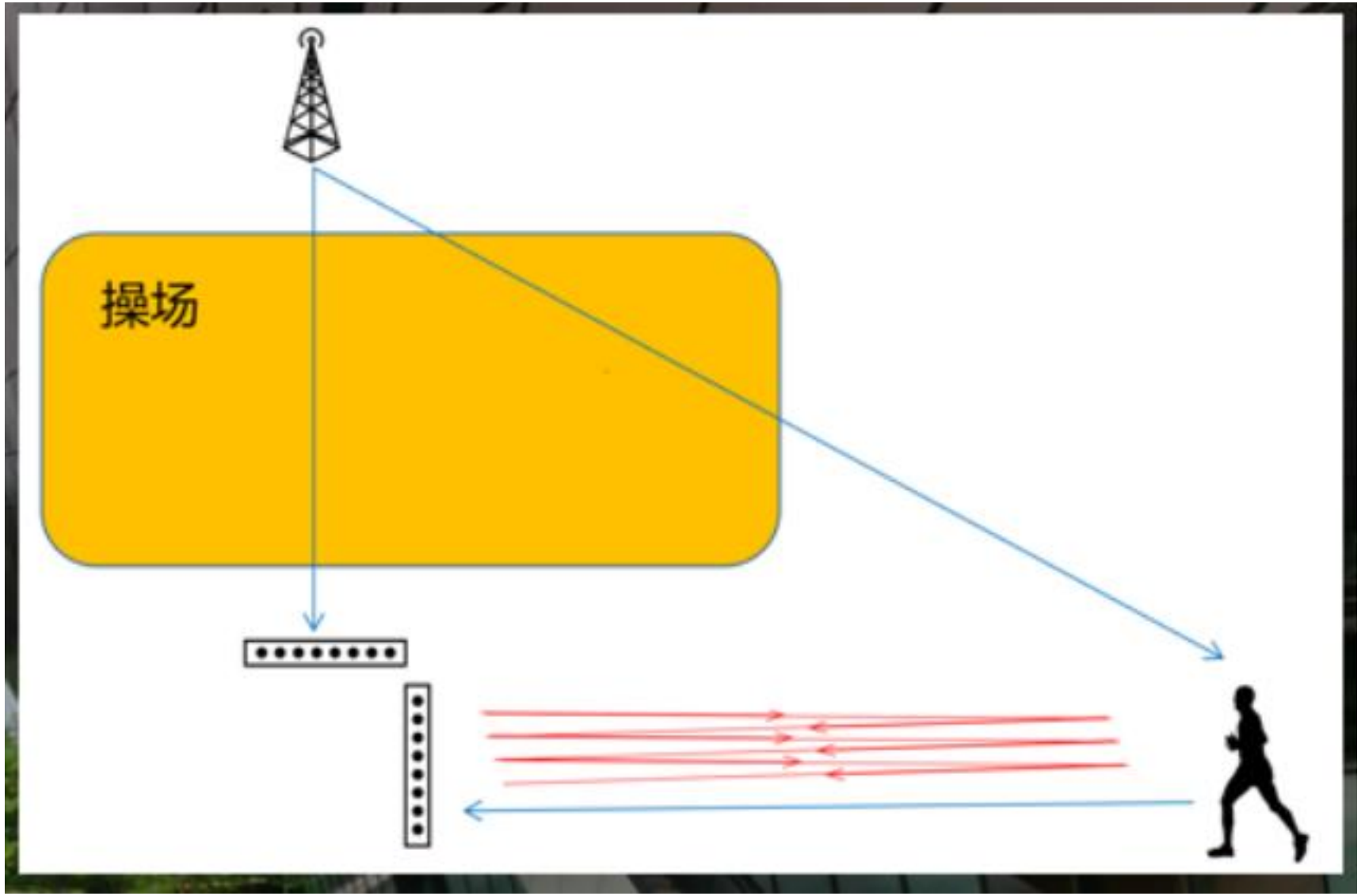
- estimate (τ, f_D):

$$(\hat{\tau}, \widehat{f_D}) = \underset{\tau, f_D}{arg\,\mathbf{max}}\, Cor(\tau, f_D)$$

- $\hat{\tau}$ is the estimate of $\boldsymbol{\tau_s - \tau_r}$, $\widehat{f_D}$ is the estimate of $\boldsymbol{f}$.

Part III: Project Tasks

Measurement Environment


操场

Project Introduction

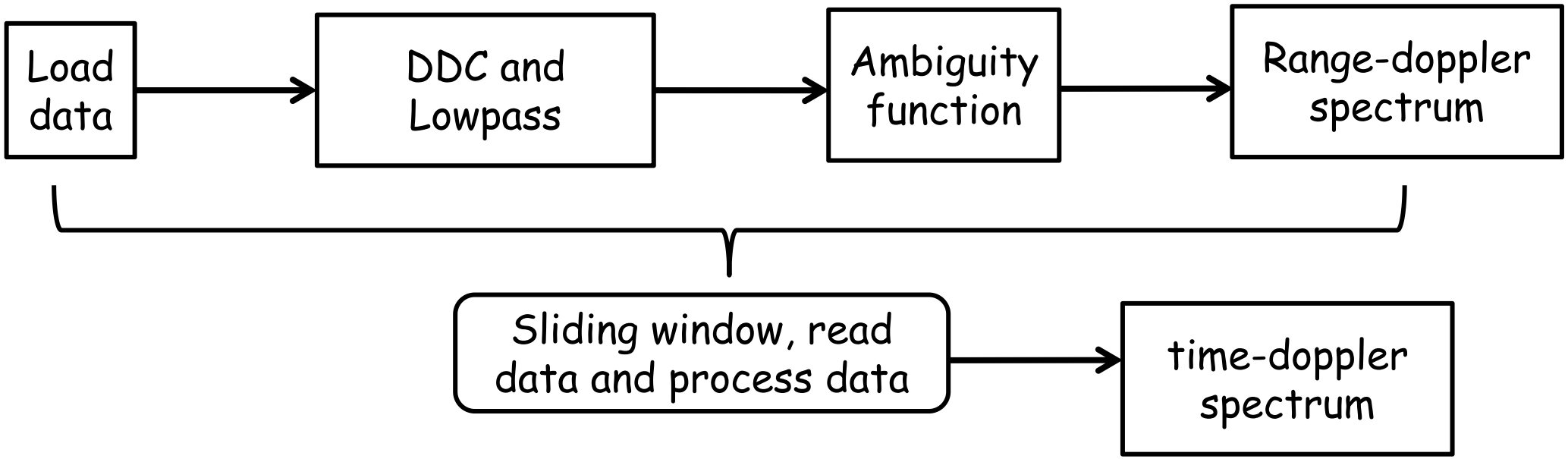
◆**Data**: two signals, one is the reference signal，the other is the surveillance signal reflected from the moving human body.

◆**Objective:**

- ✓ Basic: Estimate the $(\hat{\tau}, \widehat{f_D})$ for four sets of data and draw range-doppler spectrum.
- ✓ Optional: Obtain the relationship between the Doppler frequency caused by human motion and time, so as to figure out the mode of motion.

◆**Instructions of Transmitter:** There are two base stations with bandwidth of 20MHz(2110-2130MHz) and 5MHz(2130-2135MHz) can be seen at the experimental site. In order to ensure the accuracy of the experimental results, the base station signal with bandwidth of 5MHz needs to be eliminated from the received signal.

the Flow of Signal Processing



Load Data

```
addpath('data')
%load data_1.mat
idx_start_time =1;
load(sprintf('data/data_%d.mat',idx_start_time))
```

the Sampling rate is 25MHz

(data_1<—>0-0.5s;data_2<—>0.5s-1s;……);

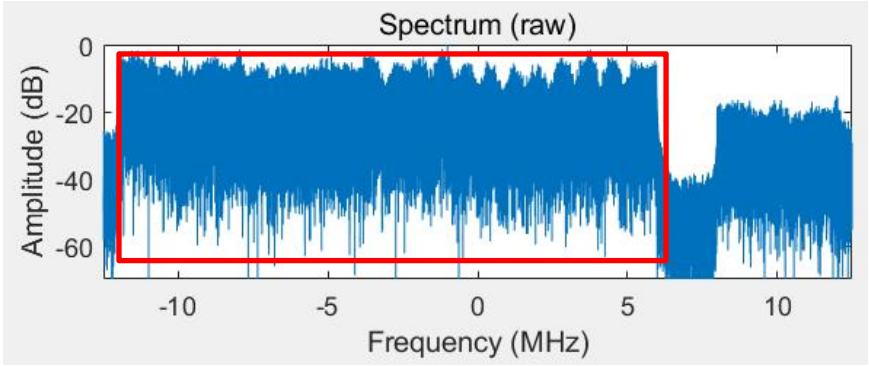
DDC and Lowpass Filter

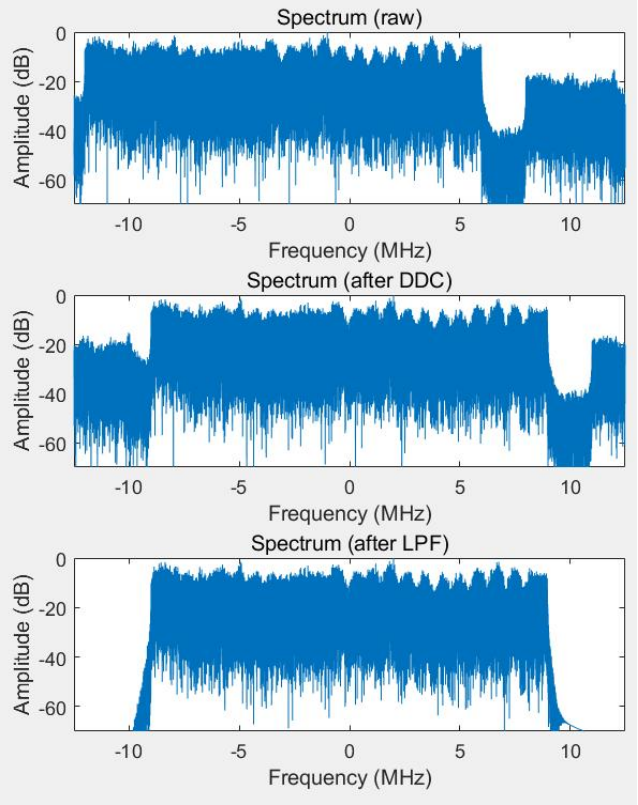
```
f_ddc = -3e6;
bandwidth = 9e6;
```

Attention: we have two base stations with bandwidth of 20MHz and 5MHz

- 2110-2130MHz
- 2130-2135MHz。

Signal spectrum





Before signal processing, we need to filter out the signal of 2130-2135MHz (5M bandwidth), and reserve the signal of 2110-2130MHz(20Mbandwidth). So we need to convert the signal 2110-2130MHz to the frequency centered on 0 Hz.Then filter out the high-frequency signal through the low-pass filter.

Ambiguity Function

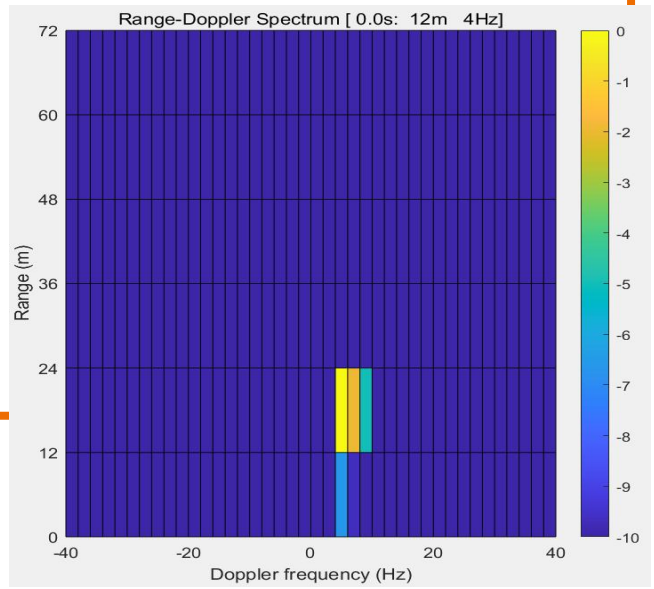
Take the segment within [t, t + T] time from the two receiving signals for ambiguilty function calculation, calculate the value of ambiguilty function by traveling all possible(τ, f_D), and select $(\hat{\tau}, \hat{f})$ corresponding to the maximum value as the estimate value.

$$Cor(\tau, f_D) = \int_t^{t+T} y_{surv}(t) y_{ref}^*(t-\tau)\, e^{-j2\pi f_D t} dt \quad \Rightarrow \quad Cor(\tau, f_D) = \sum_{n=0}^{N-1} y_{surv}[nT_s] y_{ref}^*[nT_s - \tau]\, e^{-j2\pi f_D n T_s}$$

- estimate (τ, f_D):

$$(\hat{\tau}, \hat{f}) = \arg \max_{\tau, f_D} Cor(\tau, f_D)$$

- $\hat{\tau}$ is the estimate of $\tau_s - \tau_r$, $\widehat{f_D}$ is the estimate of f .



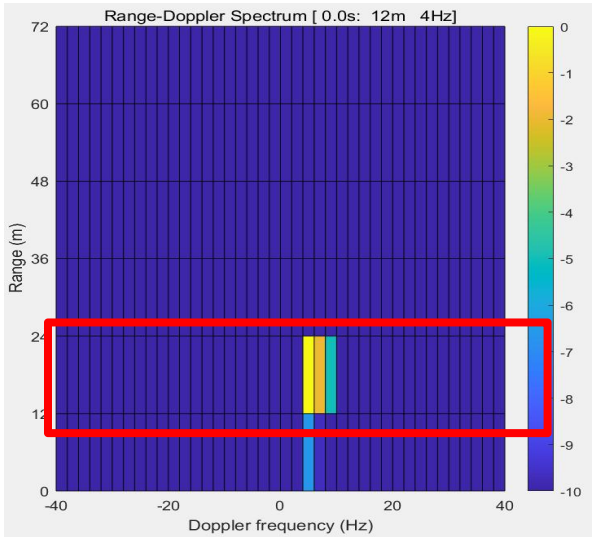
τ : traversal interval

f_D: traversal interval

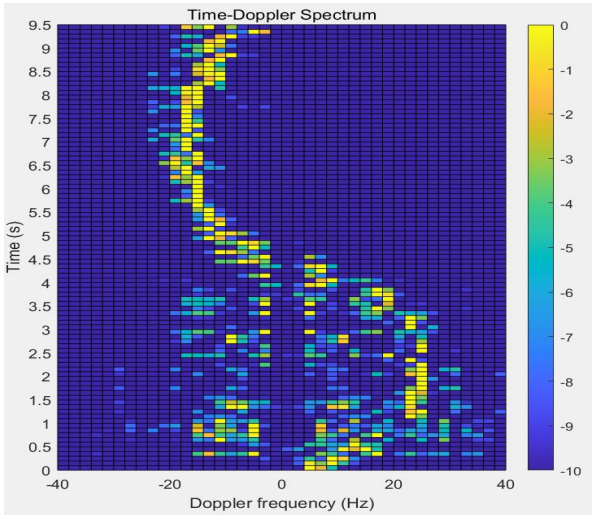
fc is 2123MHz

$$\boldsymbol{Cor}(\tau, f_D, \mathrm{t}) = \int_{\boldsymbol{t}}^{\boldsymbol{t+T}} \boldsymbol{y}_{\mathrm{sur}}(\boldsymbol{t})\boldsymbol{y}^{*}_{\mathrm{ref}}(\boldsymbol{t}-\tau)\boldsymbol{e}^{-\boldsymbol{j2\pi} f_D \boldsymbol{t}}\boldsymbol{dt}$$

t is a constant



$$\boldsymbol{Cor}(\tau, f_D, \mathrm{t}) = \int_{\boldsymbol{t}}^{\boldsymbol{t+T}} \boldsymbol{y}_{\mathrm{sur}}(\boldsymbol{t})\boldsymbol{y}^{*}_{\mathrm{ref}}(\boldsymbol{t}-\tau)\boldsymbol{e}^{-\boldsymbol{j2\pi} f_D \boldsymbol{t}}\boldsymbol{dt}$$



$$\boldsymbol{g}(\boldsymbol{d}, \boldsymbol{t}) = \max_{\tau} |Cor(\tau, f_D, \mathrm{t})|$$

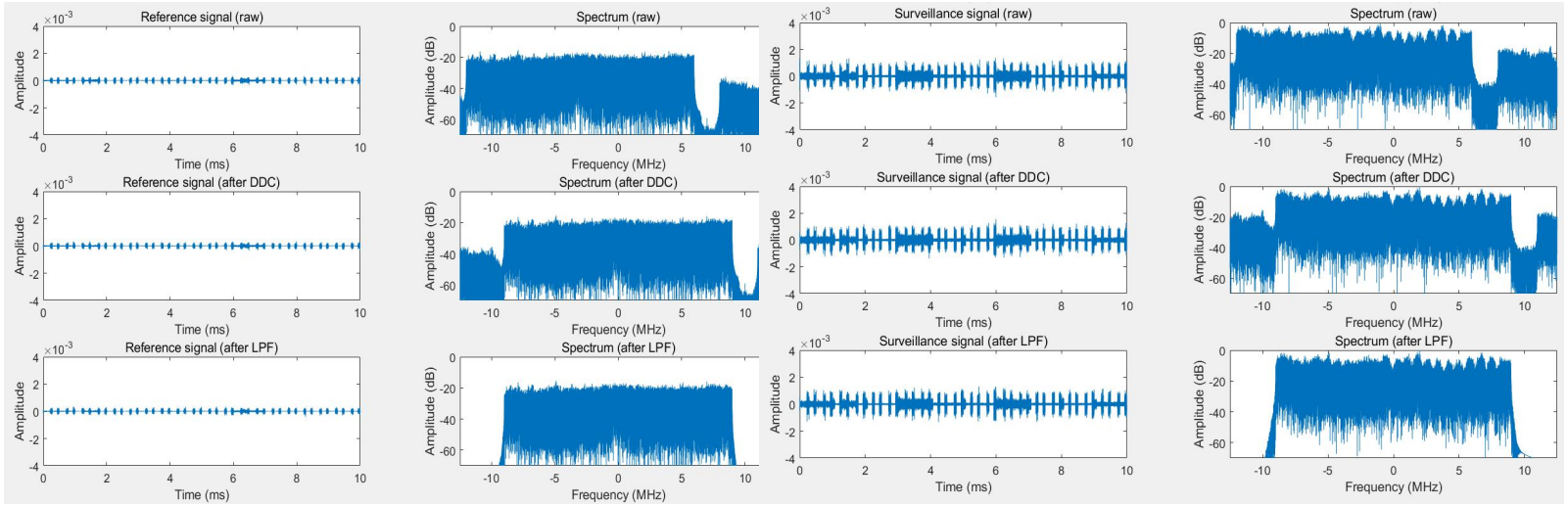
Project Tasks

Task1：For the reference signal and the surveillance signal, draw their time domain waveform and their frequency domain waveform in their following processing process respectively(**0.01s's data is OK**)：

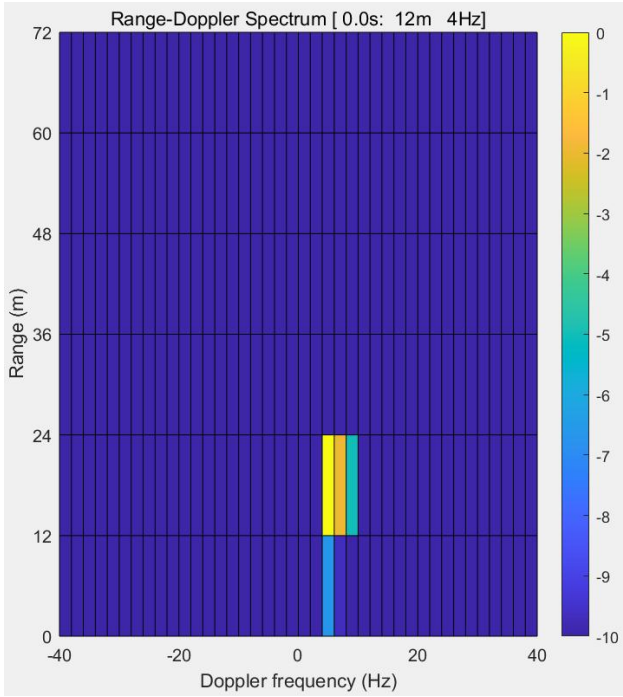
✓ Original(data_1—0-0.5s;data_2—0.5s-1s……)；

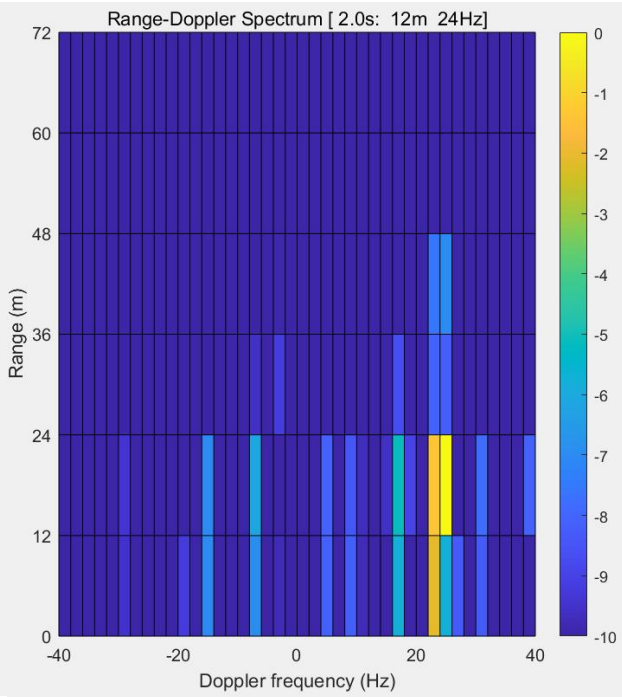
✓ After frequency conversion,；

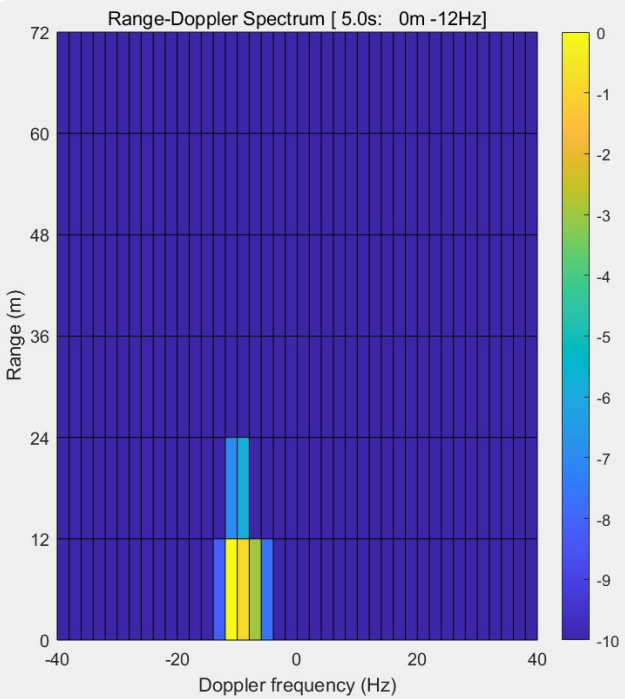
✓ After low-pass filtering；

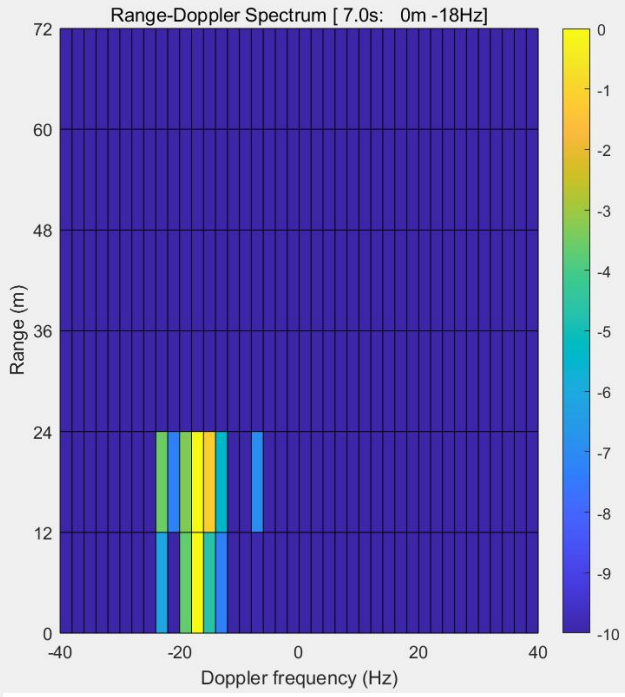


Task2：Draw the Range Doppler spectrum of the signal located at 0 ~ 0.5s, 2 ~ 2.5s, 5 ~ 5.5s and 7 ~ 7.5s(data is provided)



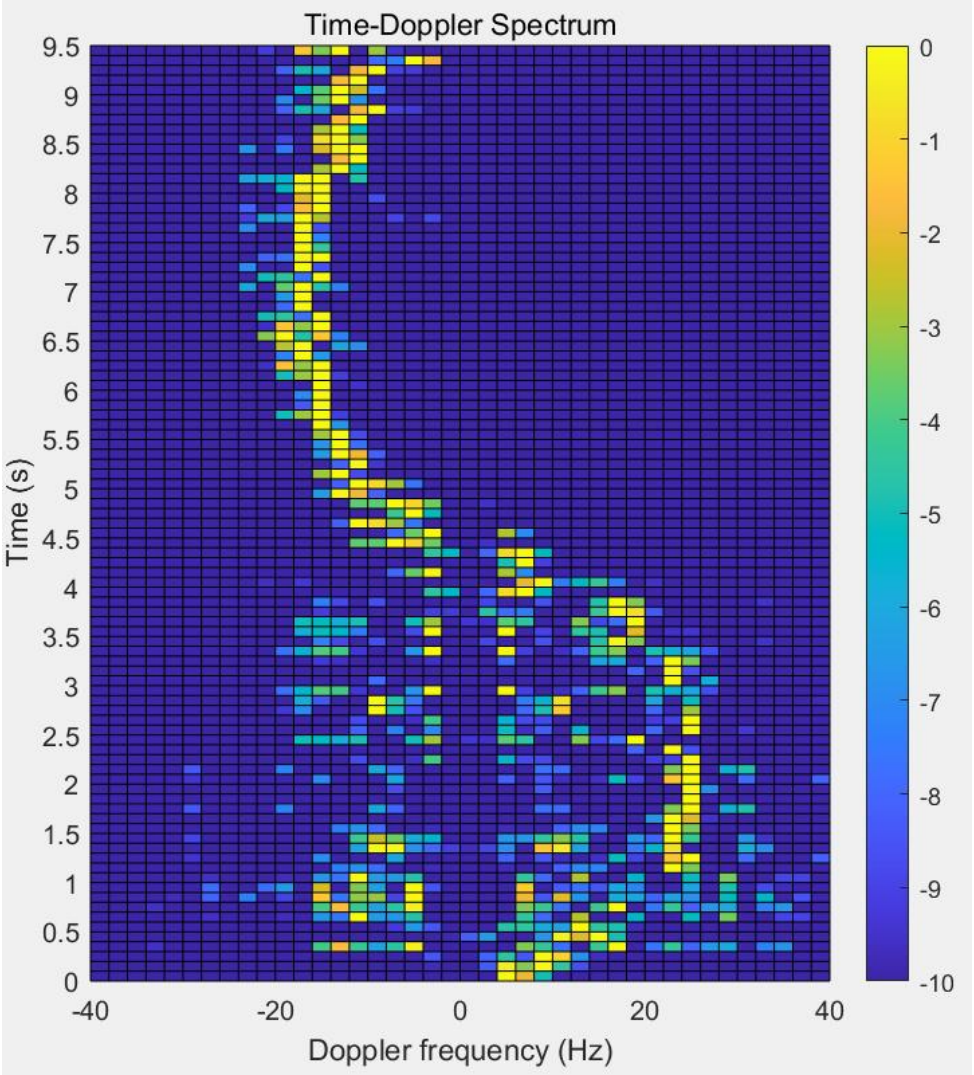






Don't be afraid, your result may not be the same

Task3：Draw the Time-Doppler spectrum of the signal



Organization

- **Each group consists of three or four students.**
- **Each group need present two Lab projects (submit reports for both projects):**
  - The presentation date is May. 12th for project 1， and June. 2nd for Project 2.
- **Each presentation is 15 minutes (including Q & A)**
  - All team members need to contribute to the presentation.
  - Presentation in English or Chinese.

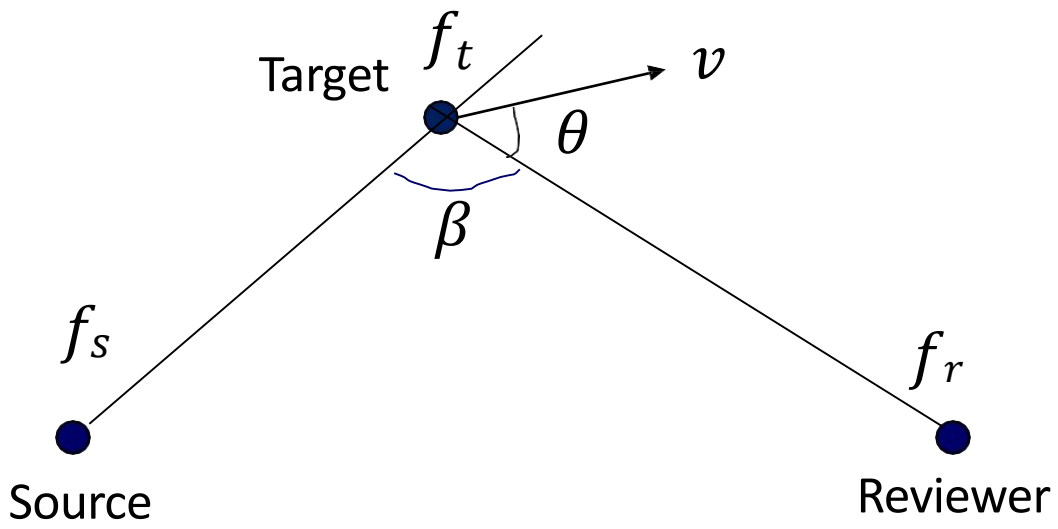
The presentation should...

- Introduce
  - team
  - objective of the project
  - background review (search more additional information)
  - methodology
- Present
  - relevant data, figure, etc.
  - the results for project tasks (e.g., with demo, Figure, etc.)
  - interpretation of project findings
- Discuss
  - what you have learned from this study?
  - problems during this project and your solution
  - investigation beyond project tasks
  - critical thinking
- Appendix (if any)
- Team effort (e.g., individual contribution)
- Reference
- Q & A (answer questions raised from audience)

Questions

About f_D

$$f' = \left(\frac{v \pm v_o}{v \mp v_s}\right) f$$



$$f_t = \frac{c + v\cos(\theta + \beta)}{c} f_s$$

$$f_r = \frac{c}{c - v\cos\theta} f_t$$

$$= \frac{c + v\cos(\theta + \beta)}{c - v\cos\theta} f_s$$

$$f_D = f_r - f_s = \frac{v\cos(\theta + \beta) + v\cos\theta}{c - v\cos\theta} f_s = \frac{v f_s}{c} \frac{\cos(\theta + \beta) + \cos\theta}{1 - \frac{v}{c}\cos\theta}$$

$$= \frac{v f_s}{c}[\cos(\theta + \beta) + \cos\theta] = \frac{2v}{\lambda_s}\cos\left(\theta + \frac{\beta}{2}\right)\cos\frac{\beta}{2}$$

$$f_D = \frac{2v}{\lambda_s} \cos\left(\theta + \frac{\beta}{2}\right) cos\frac{\beta}{2}$$

$\beta \approx 90^\circ$, $\theta = 0 \; or \; \pi$

$$f_D = \pm\frac{v}{\lambda_s}$$

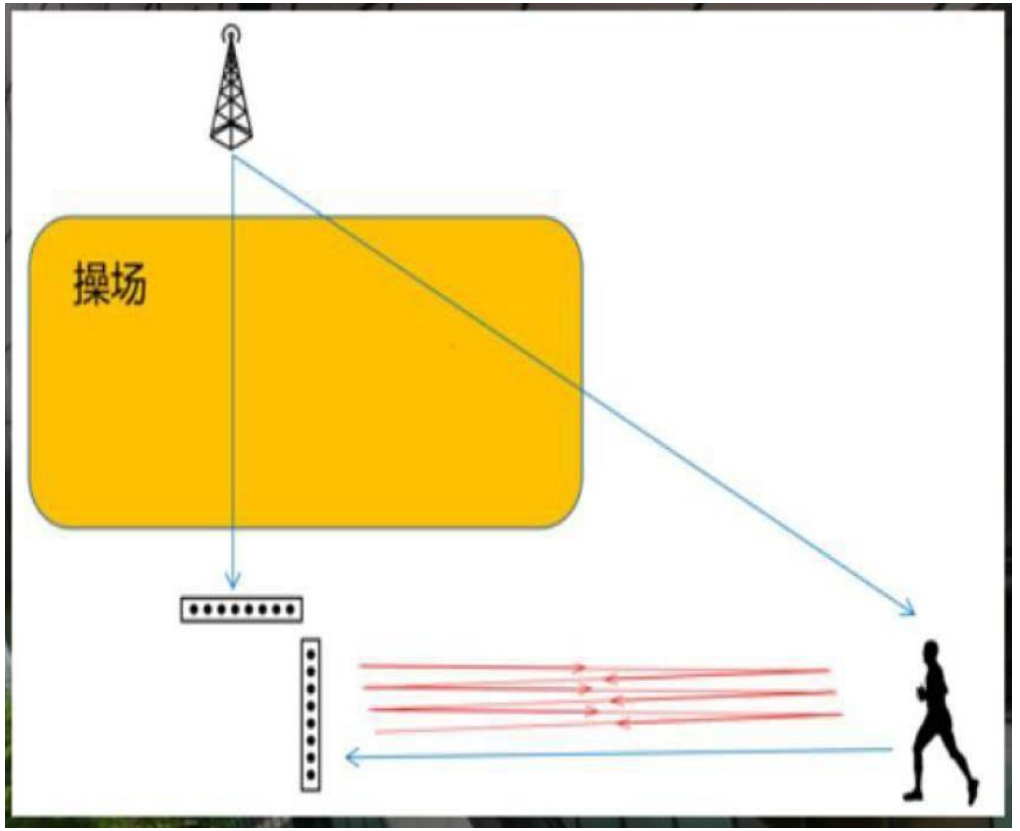


figure--Create figure window

Syntax

```
figure
figure('PropertyName',propertyvalue,...)
figure(h)
h = figure(...)
```

Properties

For a list of properties, see Figure Properties.

Description

`figure` creates a new figure window using default property values. This new figure window becomes the current figure, and it displays on top of all other figures on the screen. The title of the figure is an integer value that is not already used by an existing figure. MATLAB® saves this integer value in the figure's `Number` property.

`figure('PropertyName',propertyvalue,...)` creates a new figure window using specific property values. For a list of available properties, see Figure Properties. MATLAB uses default values for any properties that you do not explicitly define as arguments.

`figure(h)` does one of the following:

- If `h` is the handle or the `Number` property value of an existing figure, then `figure(h)` makes that existing figure the current figure, makes it visible, and moves it on top of all other figures on the screen. The current figure is the target for graphics output.
- If `h` is not the handle and is not the `Number` property value of an existing figure, but is an integer, then `figure(h)` creates a figure object and assigns its `Number` property the value `h`.
- If `h` is not the handle to a figure and is not a positive integer, then MATLAB returns an error.

`h = figure(...)` returns the handle to the figure object.

Figure Properties

Control appearance and behavior of figure window

expand all in page

Figures are windows that contain graphics or user interface components. Figure properties control the appearance and behavior of a particular instance of a figure. To modify aspects of a figure, change property values.

Starting in R2014b, you can use dot notation to query and set properties.

```
fig = figure;
u = fig.Units;
fig.Units = 'inches';
```

If you are using an earlier release, use the `get` and `set` functions instead.

Figure Appearance

expand all

`Color` — Figure window background color
RGB triplet | short name | long name | `'none'`

`DockControls` — Interactive figure docking
`'on'` (default) | `'off'`

`MenuBar` — Figure menu bar display
`'figure'` (default) | `'none'`

get--Query graphics object properties
gcf--Current figure handle
gca--Current axes handle
gco--Handle of current object
gcp--Get current parallel pool
set--Set graphics object properties

saveas--Save figure to specific file format

Syntax

```
saveas(fig,filename)
saveas(fig,filename,formattype)
```

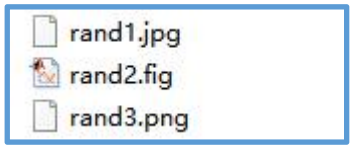
Description

`saveas(fig,filename)` saves the figure or Simulink® block diagram specified by `fig` to file `filename`. Specify the file name as a character vector that includes a file extension, for example, `'myplot.jpg'`. The file extension defines the file format. If you do not specify an extension, then `saveas` saves the figure to a FIG-file.To save the current figure, specify `fig` as `gcf`.

`saveas(fig,filename,formattype)` creates the file using the specified file format, `formattype`. If you do not specify a file extension in the file name, for example, `'myplot'`, then the standard extension corresponding to the specified format automatically appends to the file name. If you specify a file extension, it does not have to match the format. `saveas` uses `formattype` for the format, but saves the file with the specified extension. Thus, the file extension might not match the actual format used.

print--Print figure or save to specific file format
savefig--Save figure and contents to FIG-file

```
clc,clear,close all

scrsz =get(0,'ScreenSize')
figure1=figure('Position',[0 30 scrsz(3) scrsz(4)-95])

%生成数据
x=rand(100,1)
%画图保存
plot(x)
saveas(figure1,'rand1','jpg')

savefig(figure1,'rand2')

print('rand3','-dpng')
```



sprintf--Format data into string

Syntax

```
str = sprintf(formatSpec,A1,...,An)
[str,errmsg] = sprintf(formatSpec,A1,...,An)
```

Description

`str = sprintf(formatSpec,A1,...,An)` formats the data in arrays `A1,...,An` according to `formatSpec` in column order, and returns the results to `str`.

`[str,errmsg] = sprintf(formatSpec,A1,...,An)` returns an error message as a character vector when the operation is unsuccessful. Otherwise, `errmsg` is empty.

imagesc--Display image with scaled colors

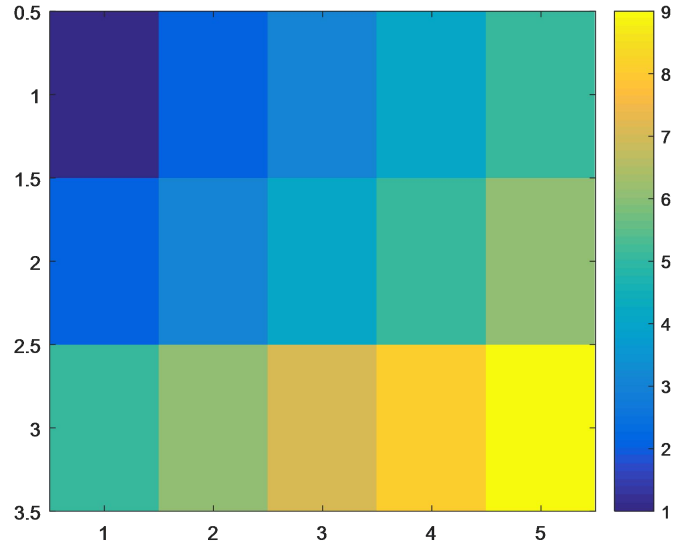
Syntax

`imagesc(C)` example

`imagesc(x,y,C)` example

`imagesc(x,y,C)` specifies the image location. Use `x` and `y` to specify the locations of the corners corresponding to `C(1,1)` and `C(m,n)`. To specify both corners, set `x` and `y` as two-element vectors. To specify the first corner and let `imagesc` determine the other, set `x` and `y` as scalar values. The image is stretched and oriented as applicable.

```
close all
x=[1 2 3 4 5];
y=[1 2 3 ];
C=[1 2 3 4 5;2 3 4 5 6;5 6 7 8 9;]
imagesc(x,y,C)
colorbar
```



meshgrid--2-D and 3-D grids

Syntax

```
[X,Y] = meshgrid(x,y)
[X,Y] = meshgrid(x)

[X,Y,Z] = meshgrid(x,y,z)
[X,Y,Z] = meshgrid(x)
```

Description

`[X,Y] = meshgrid(x,y)` returns 2-D grid coordinates based on the coordinates contained in vectors `x` and `y`. `X` is a matrix where each row is a copy of `x`, and `Y` is a matrix where each column is a copy of `y`. The grid represented by the coordinates `X` and `Y` has `length(y)` rows and `length(x)` columns.

`[X,Y] = meshgrid(x)` is the same as `[X,Y] = meshgrid(x,x)`, returning square grid coordinates with grid size `length(x)`-by-`length(x)`.

`[X,Y,Z] = meshgrid(x,y,z)` returns 3-D grid coordinates defined by the vectors `x`, `y`, and `z`. The grid represented by `X`, `Y`, and `Z` has size `length(y)`-by-`length(x)`-by-`length(z)`.

`[X,Y,Z] = meshgrid(x)` is the same as `[X,Y,Z] = meshgrid(x,x,x)`, returning 3-D grid coordinates with grid size `length(x)`-by-`length(x)`-by-`length(x)`.

surf--3-D shaded surface plot

Syntax

```
surf(Z)
surf(Z,C)
surf(X,Y,Z)
surf(X,Y,Z,C)
surf(...,'PropertyName',PropertyValue)
surf(ax,...)
h = surf(...)
```

Description

`surf(Z)` creates a three-dimensional shaded surface from the `Z` components in matrix `Z`, using `x = 1:n` and `y = 1:m`, where `[m,n] = size(Z)`. The height, `Z`, is a single-valued function defined over a geometrically rectangular grid. `Z` specifies the color data, as well as surface height, so color is proportional to surface height. The values in `Z` can be numeric or datetime or duration values.

`surf(Z,C)` plots the height of `Z`, a single-valued function defined over a geometrically rectangular grid, and uses matrix `C`, assumed to be the same size as `Z`, to color the surface. See Coloring Mesh and Surface Plots for information on defining `C`.

`surf(X,Y,Z)` uses `Z` for the color data and surface height. `X` and `Y` are vectors or matrices defining the `x` and `y` components of a surface. If `X` and `Y` are vectors, `length(X) = n` and `length(Y) = m`, where `[m,n] = size(Z)`. In this case, the vertices of the surface faces are *(X(j), Y(i), Z(i,j))* triples. To create `X` and `Y` matrices for arbitrary domains, use the `meshgrid` function. The values in `X`, `Y`, or `Z` can be numeric or datetime or duration values.

`surf(X,Y,Z,C)` uses `C` to define color. MATLAB® performs a linear transformation on this data to obtain colors from the current colormap.

`surf(...,'PropertyName',PropertyValue)` specifies surface properties along with the data. For a list of properties, see Chart Surface Properties.

`surf(ax,...)` plots into the axes `ax` instead of the current axes (`gca`).

`h = surf(...)` returns a handle to a chart surface graphics object.

view--Viewpoint specification

Syntax

```
view(az,el)
view([az,el])
view([x,y,z])
view(2)
view(3)
view(ax,...)
[az,el] = view
```

Description

The position of the viewer (the viewpoint) determines the orientation of the axes. You specify the viewpoint in terms of azimuth ar
in three-dimensional space.

`view(az,el)` and `view([az,el])` set the viewing angle for a three-dimensional plot. The azimuth, `az`, is the horizontal rotation a
measured in degrees from the negative *y*-axis. Positive values indicate counterclockwise rotation of the viewpoint. `el` is the vertic
viewpoint in degrees. Positive values of elevation correspond to moving above the object; negative values correspond to moving

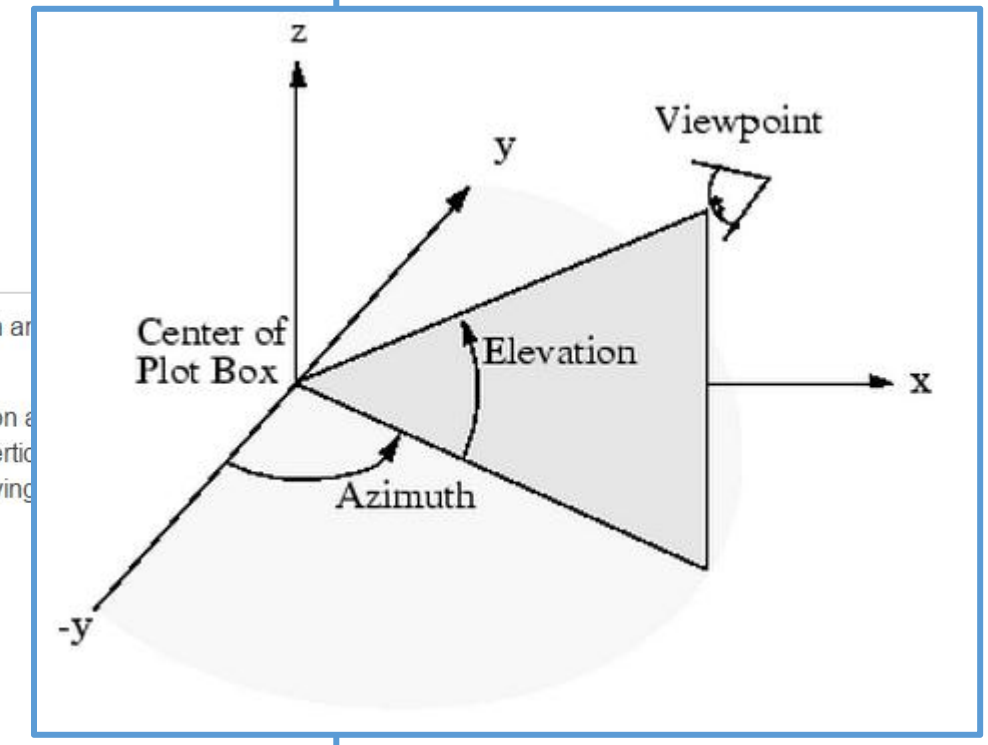
`view([x,y,z])` sets the view direction to the Cartesian coordinates `x`, `y`, and `z`. The magnitude of `(x,y,z)` is ignored.

`view(2)` sets the default two-dimensional view, `az = 0`, `el = 90`.

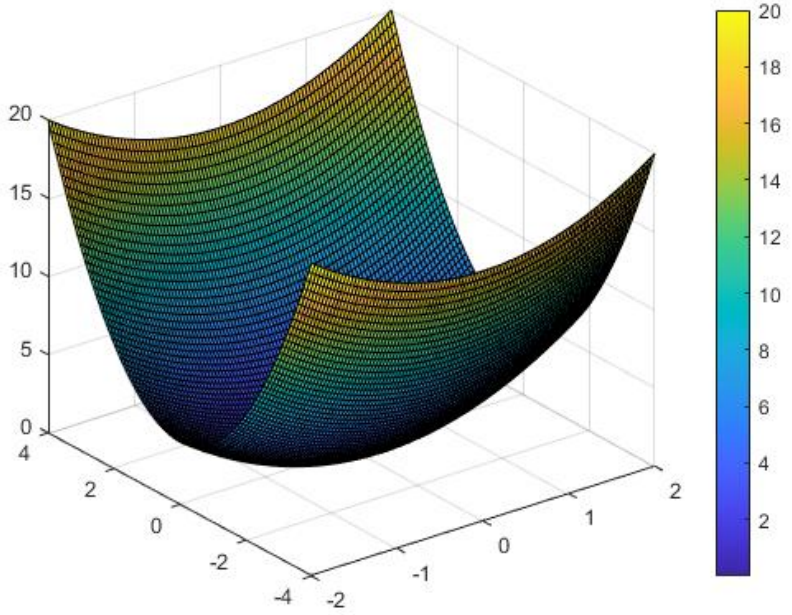
`view(3)` sets the default three-dimensional view, `az = -37.5`, `el = 30`.

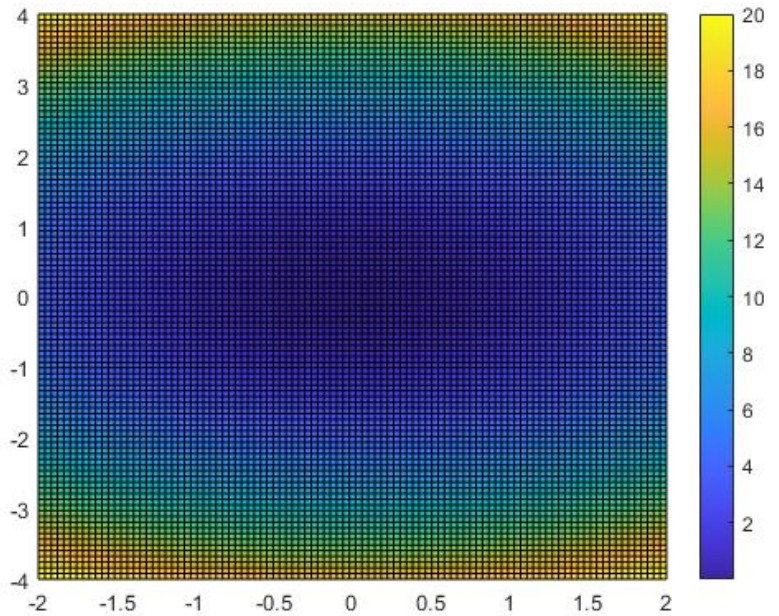
`view(ax,...)` uses axes `ax` instead of the current axes.

`[az,el] = view` returns the current azimuth and elevation.



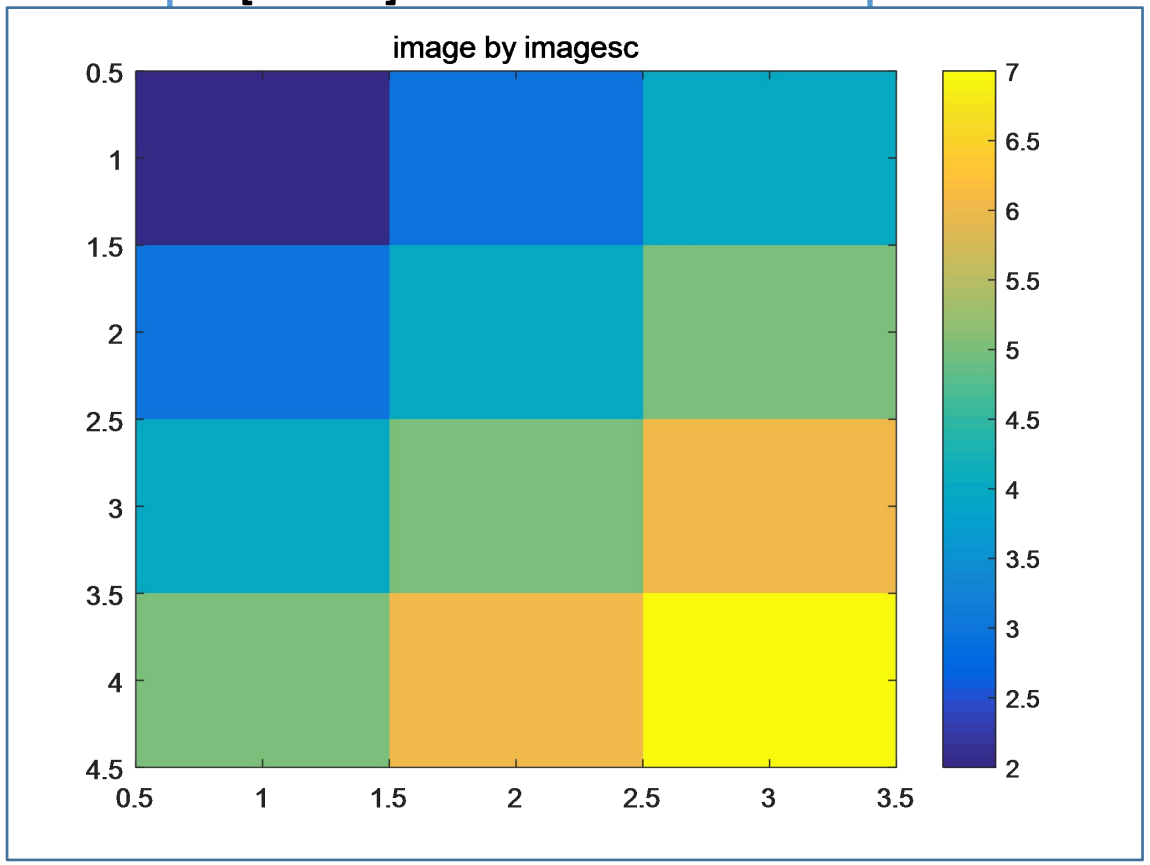
```
clc,clear,close all
x = linspace(-2,2,100)
y = linspace(-4,4,100)

[X,Y] = meshgrid(x,y)

% grid.
Z= X.^2+Y.^2;
figure
surf(X,Y,Z),colorbar
[az el]=view

figure
surf(X,Y,Z),colorbar
view(0,90)
```





imagesc VS surf

```
clc,clear,close all
m=[1 2 3]
n=[1 2 3 4]
```




```
[X,Y]=meshgrid(m,n)
figure
surf(X,Y,v)
```