Principles of Communications

ECS 332

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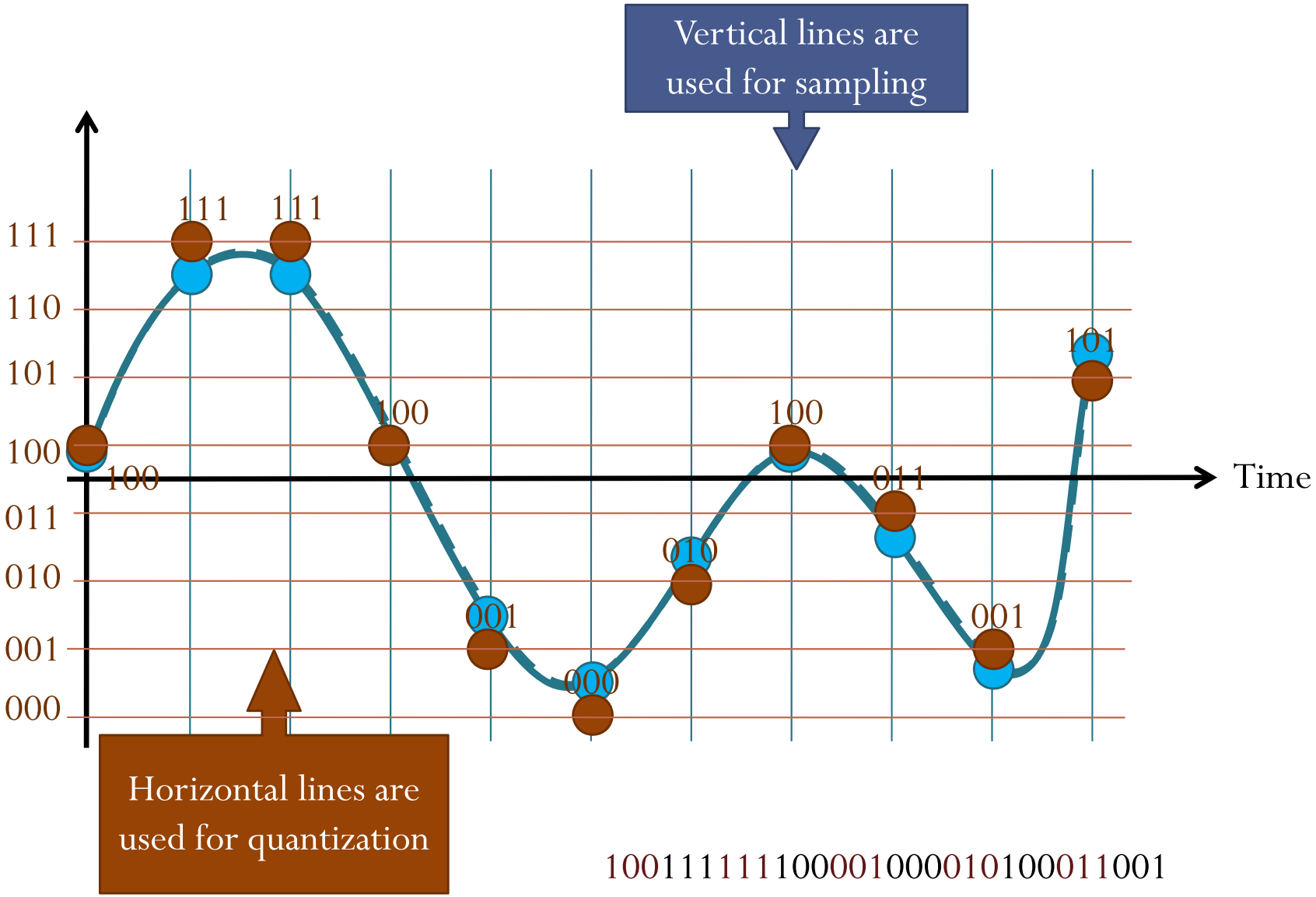
6. Sampling and Reconstruction

Office Hours:

BKD, 6th floor of Sirindhralai building

Wednesday	**14:00-15:30**
Friday	**14:00-15:30**

Digitization (analog to digital)



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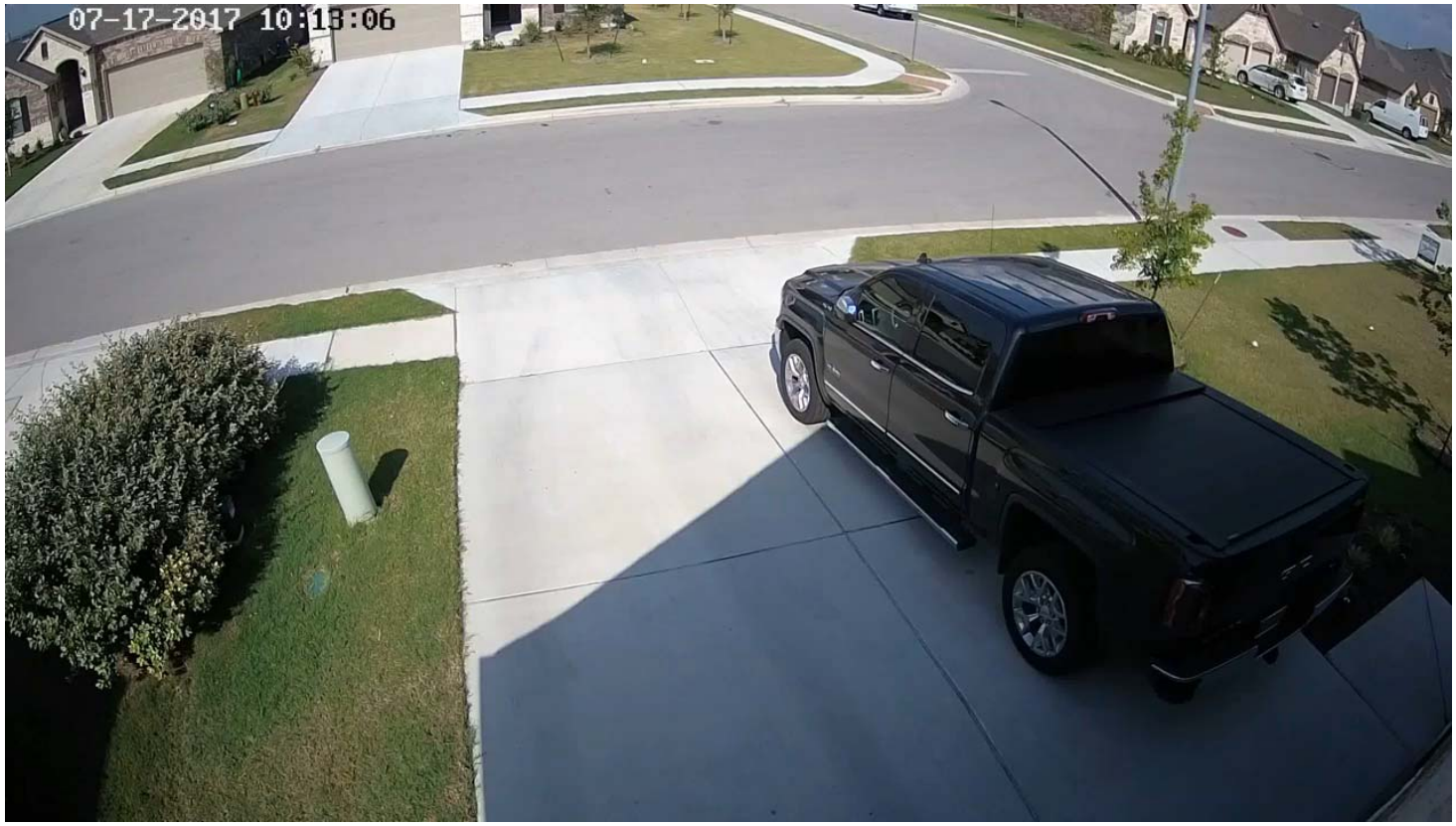
6.1 Sampling

A bird's mind-boggling stunt?

- Viewed over 250k times in just 24 hours after a YouTuber uploaded it to the internet.



[http://www.boredpanda.com/camera-frame-rate-synced-bird-wings/?utm_source=CB11&utm_medium=link&utm_campaign=SAW]

A magically hovering helicopter?

Figure 44

Sampling

- Start with a continuous-time (analog) signal.

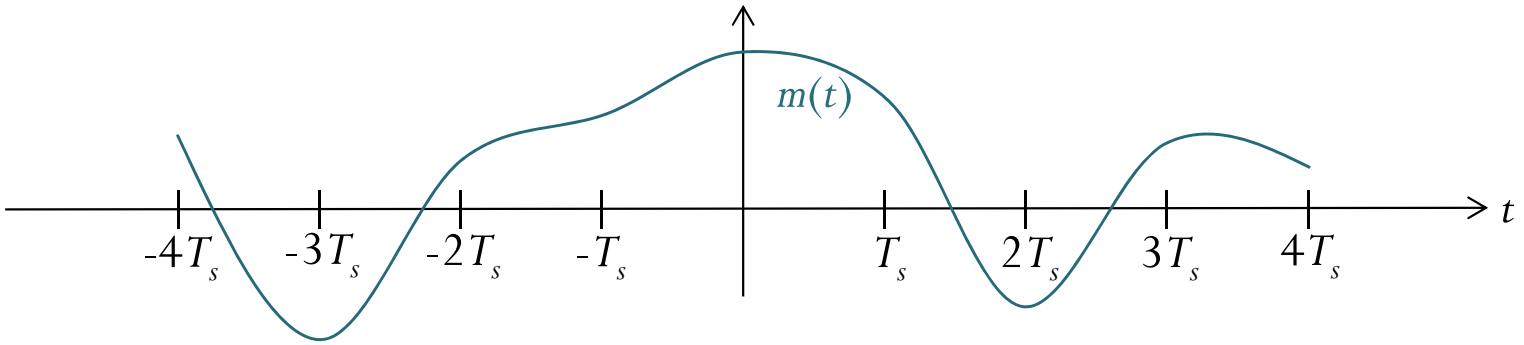


Figure 44

Sampling

- Record the value every T_s seconds.

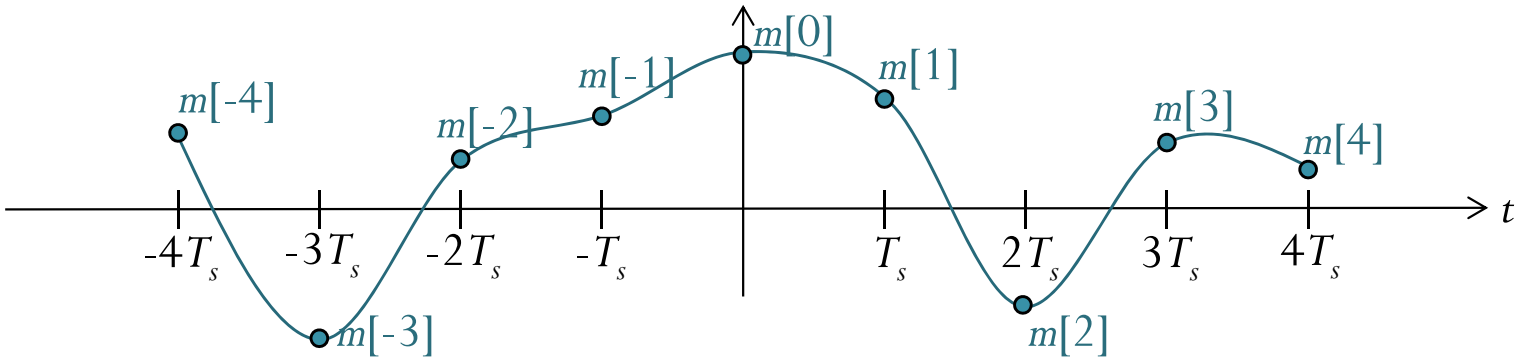
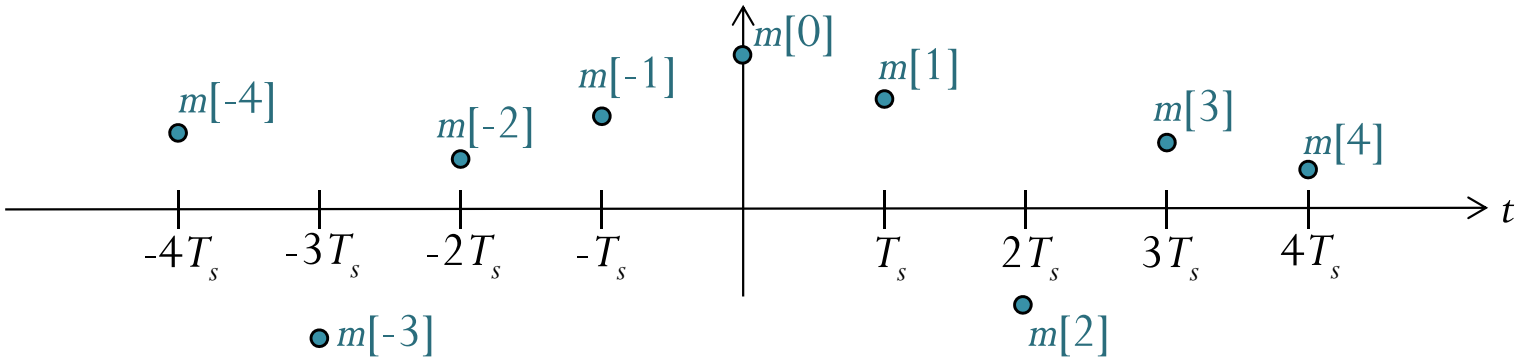


Figure 44

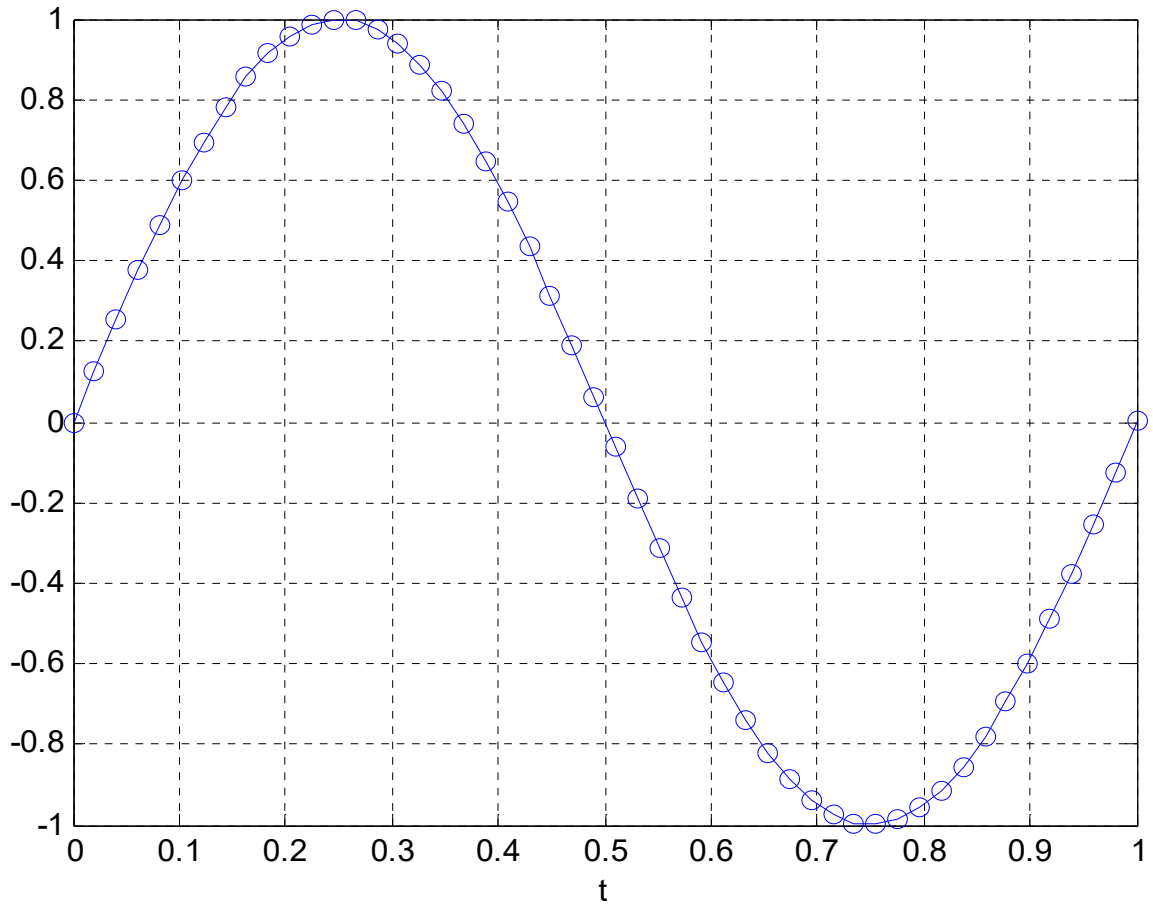
Sampling

- Get a sequence of samples (numbers).



Example: Plotting sin(100πt) (1/6)

This is the plot of sin(100πt). What's wrong with it?

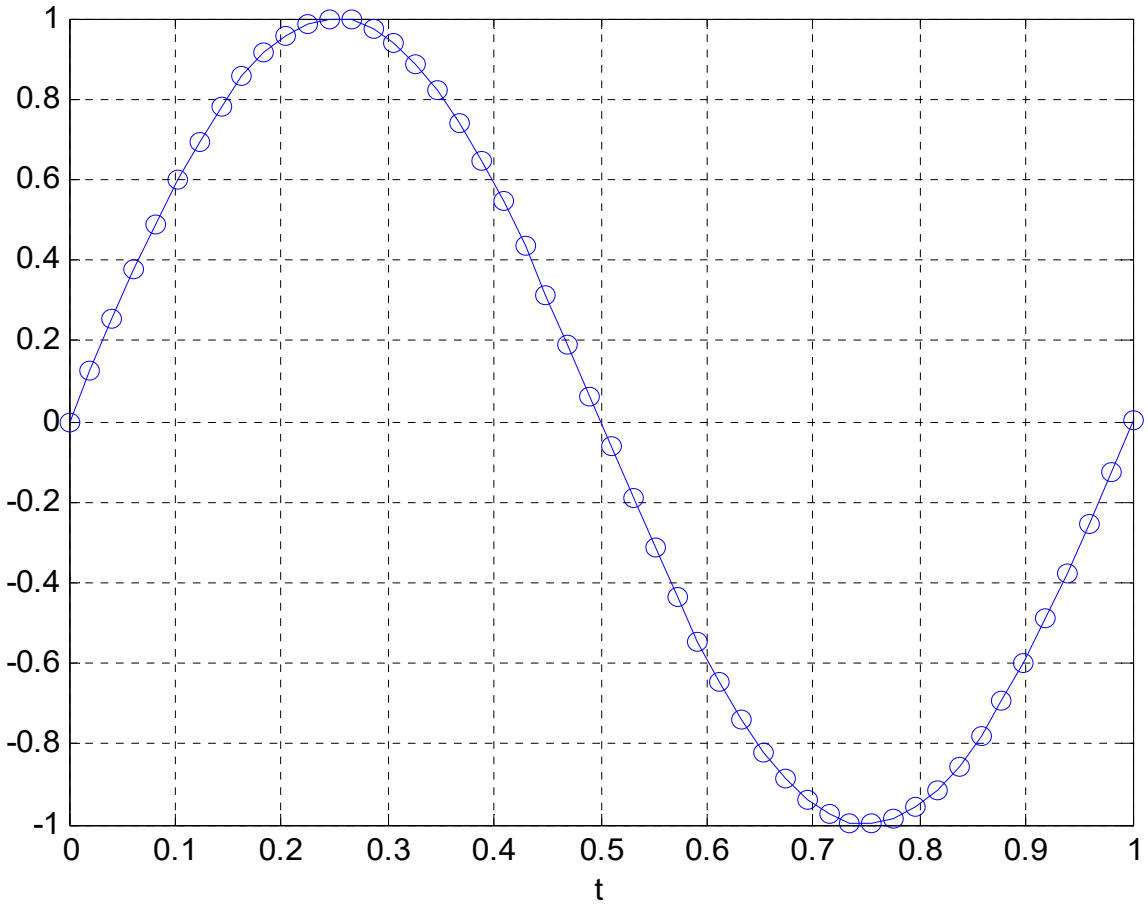


[AliasingSin_FirstEx.m]

Example: Plotting sin(100πt) (2/6)

- Plot 50 points from 0 to 1.

```
close all; clear all;
fs = 49;
ET = 1;
t = 0:1/fs:ET;
x = sin(100*pi*t);
plot(t,x,'-o'); grid on
xlabel('t')
```



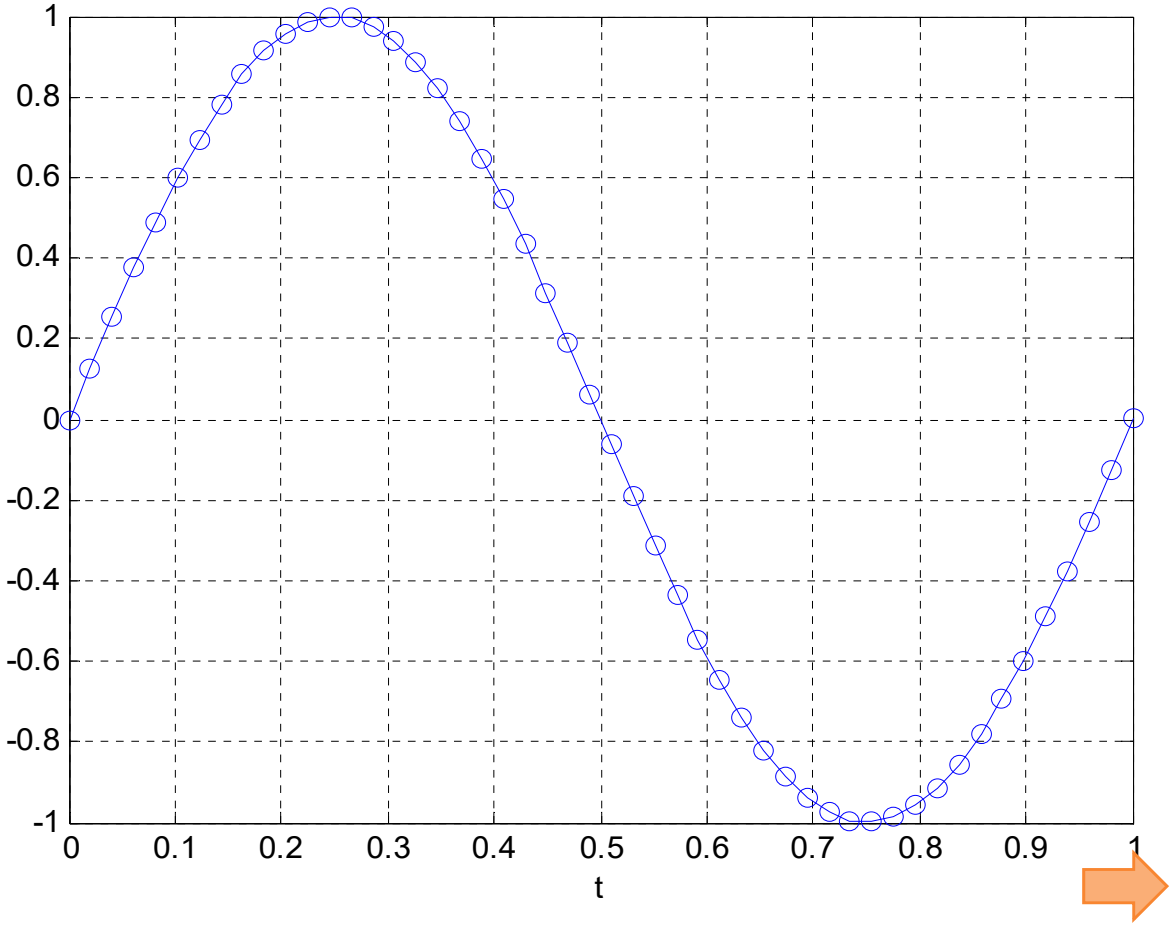
Example: Plotting sin(100πt) (3/6)

Signal of the form $\sin(2\pi f_0 t)$ have frequency $f = f_0$ Hz.

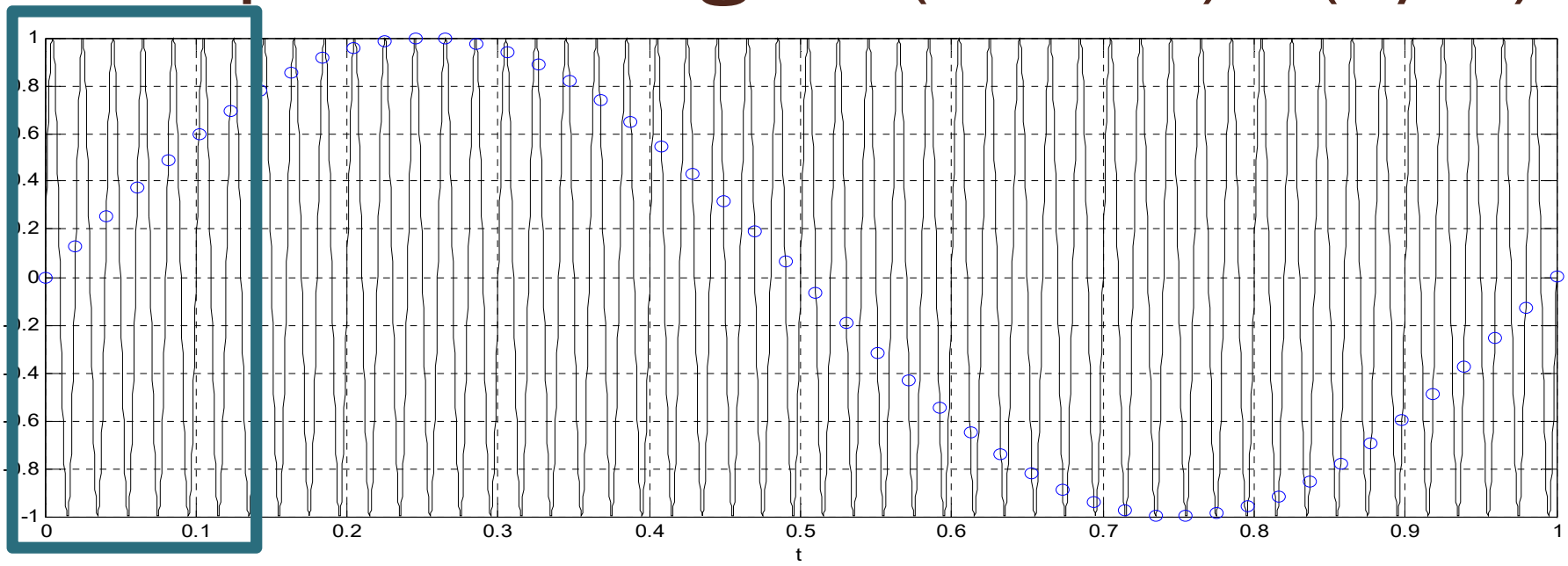
So, the frequency of $\sin(100\pi t)$ is 50 Hz.

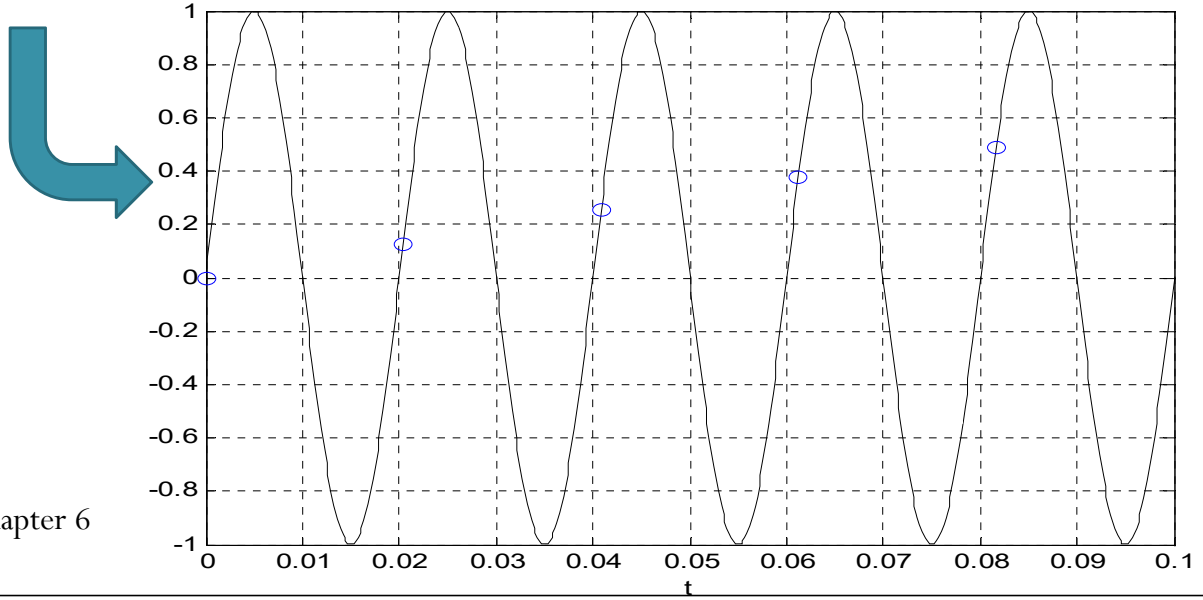
From time 0 to 1, it should have completed 50 cycles. However, our plot has only one cycle.

It looks more like the plot of $\sin(2\pi t)$



Example: Plotting sin(100πt) (4/6)



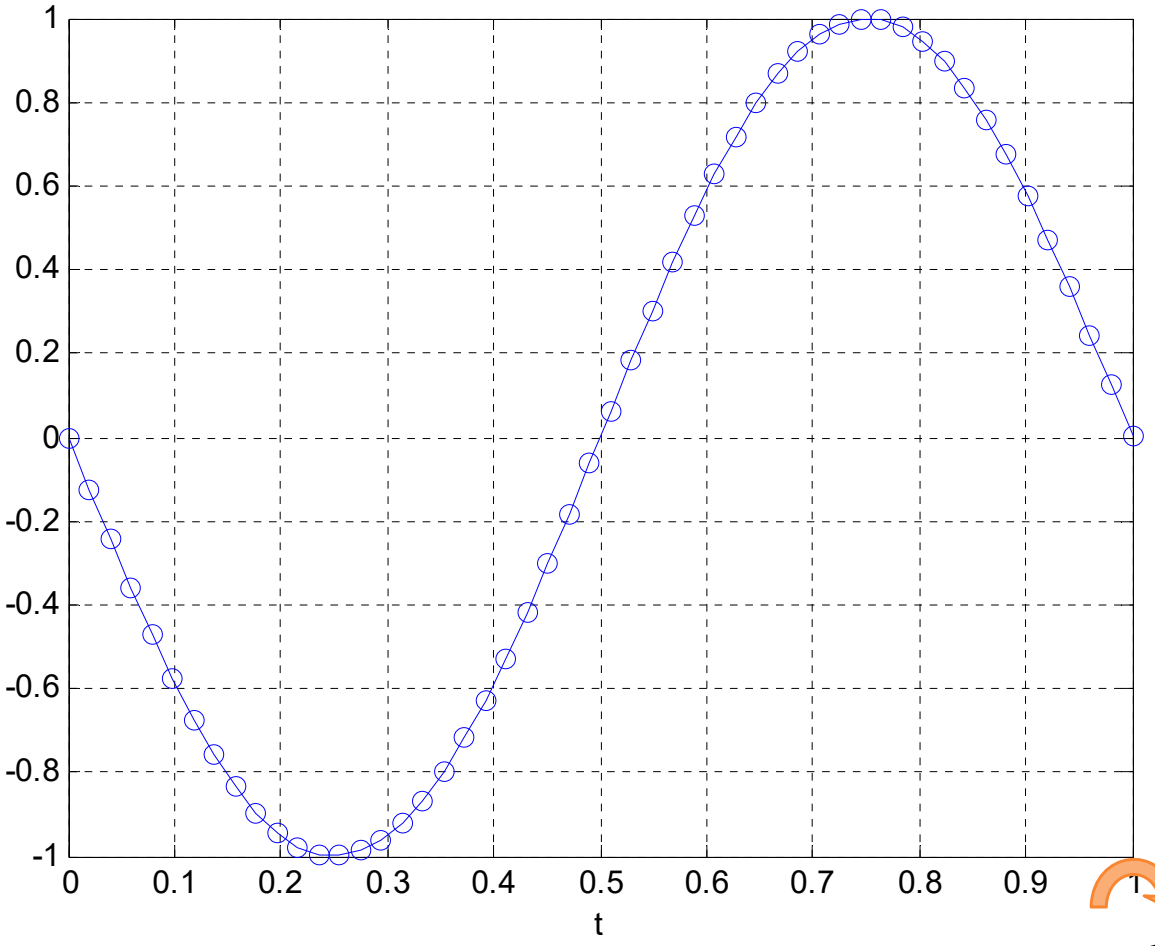


Aliasing causes high-frequency signal to be seen as low frequency.

Example: Plotting sin(100πt) (5/6)

- Plot 52 points from 0 to 1.

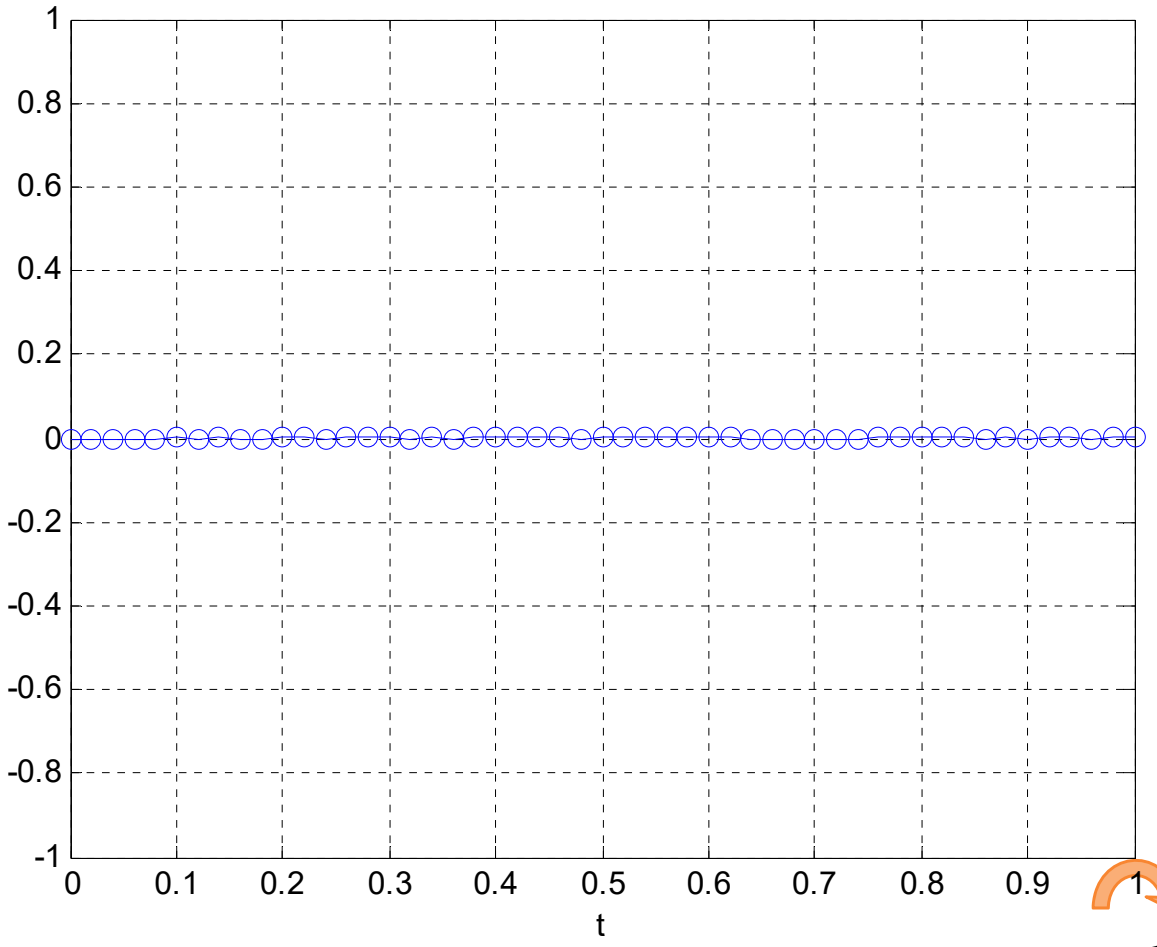
```
close all; clear all;
fs = 51;
ET = 1;
t = 0:1/fs:ET;
x = sin(100*pi*t);
plot(t,x,'-o'); grid on
xlabel('t')
```



Example: Plotting sin(100πt) (6/6)

- Plot 51 points from 0 to 1.

```
close all; clear all;
fs = 50;
ET = 1;
t = 0:1/fs:ET;
x = sin(100*pi*t);
plot(t,x,'-o'); grid on
xlabel('t')
ylim([-1 1])
```

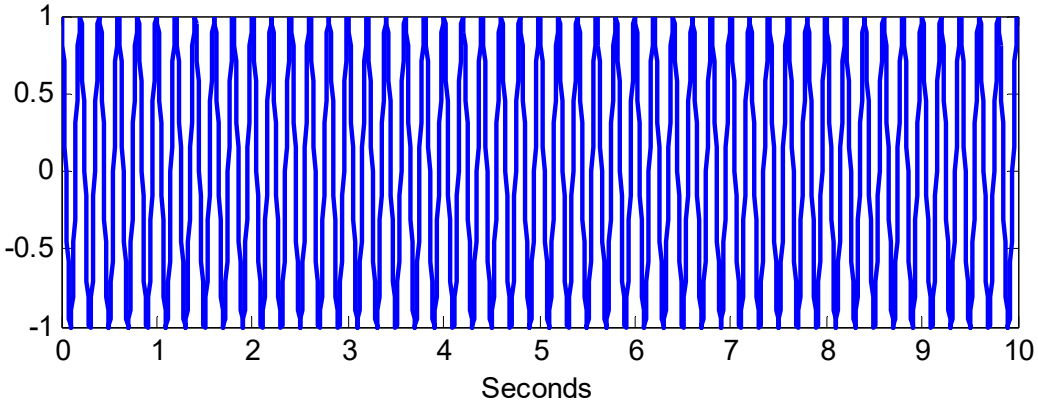


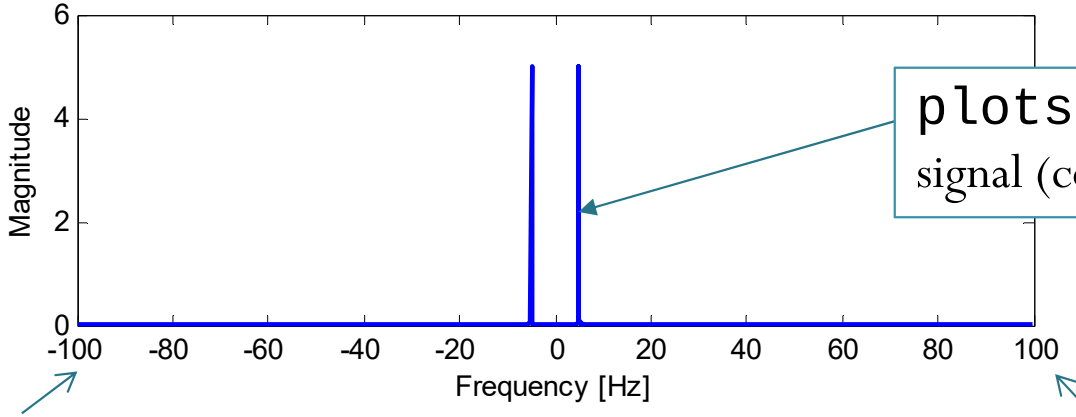
Example 6.10

Using plotspect.m to study aliasing

- f_s: Sampling frequency = 200 samples/sec

$\cos(2\pi(5)t)$





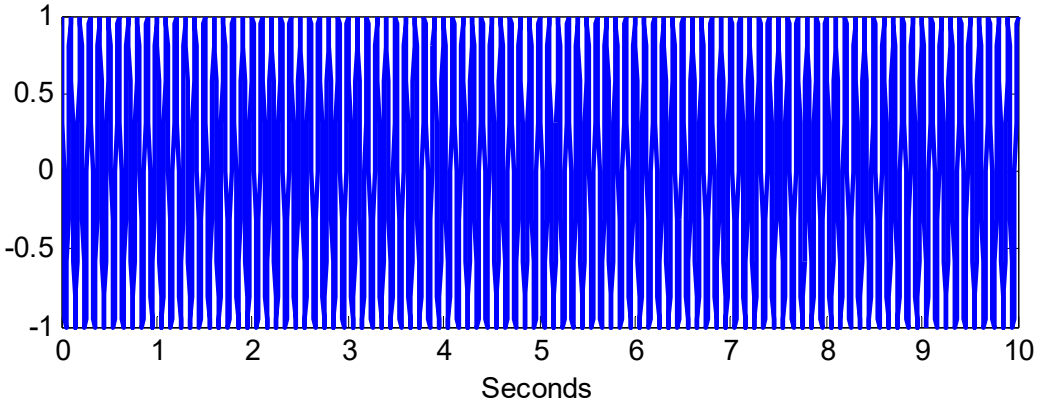
`plotspect` sees 5 Hz signal (correct)

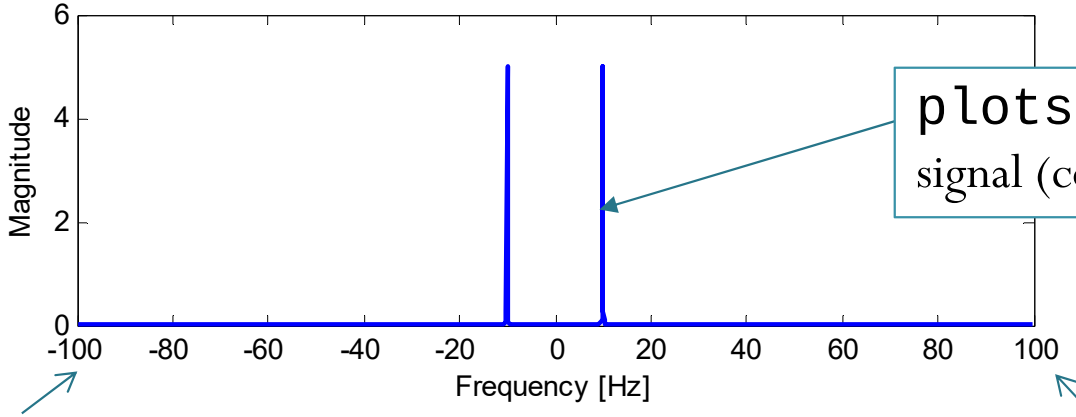
$-\frac{f_s}{2}$ $\frac{f_s}{2}$

Using plotspect.m to study aliasing

- f_s: Sampling frequency $= 200$ samples/sec

$\cos(2\pi(10)t)$



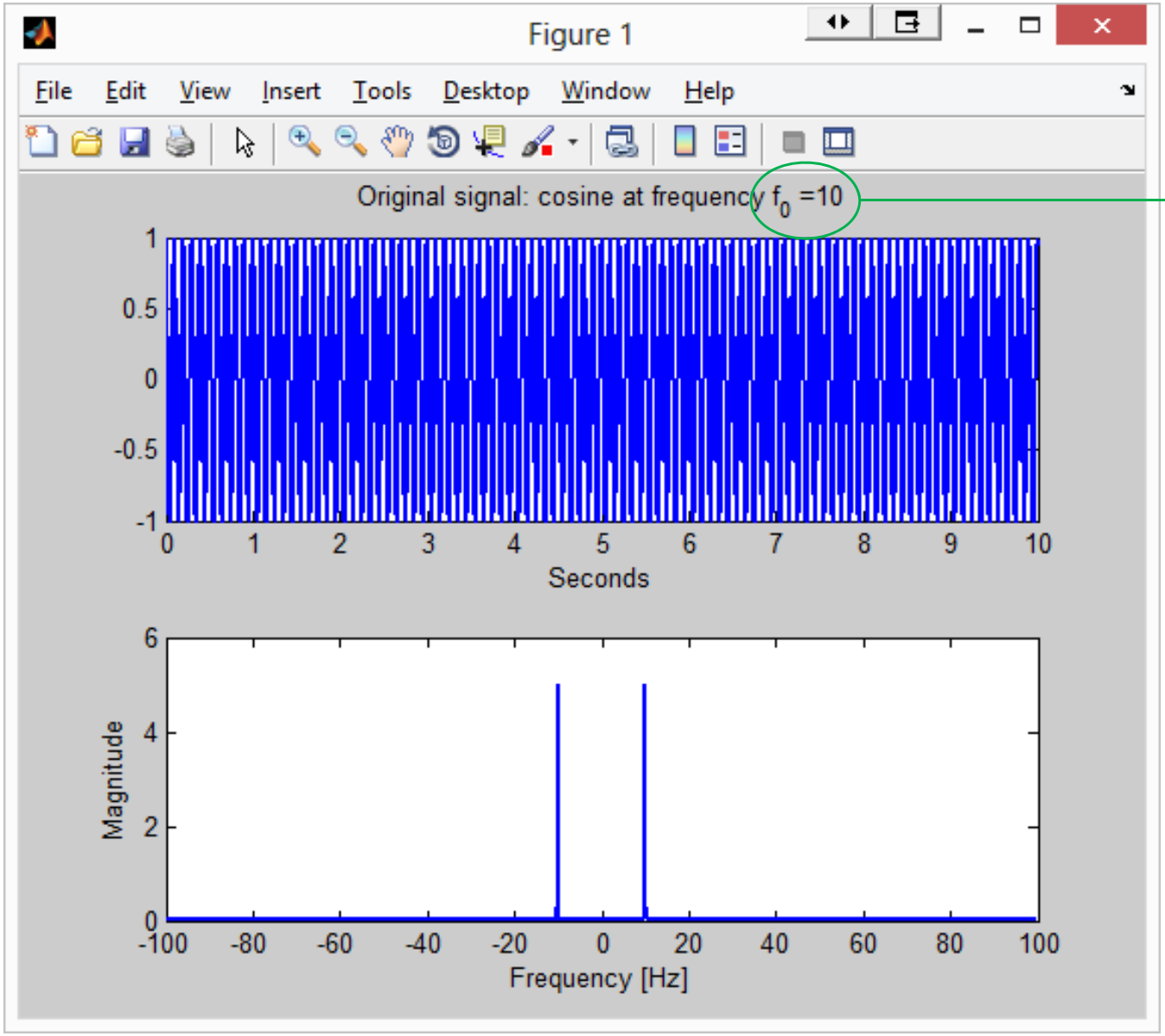


`plotspect` sees 10 Hz signal (correct)

$-\frac{f_s}{2}$ $\frac{f_s}{2}$

MATLAB Demo

f_s: Sampling frequency = 200 samples/sec

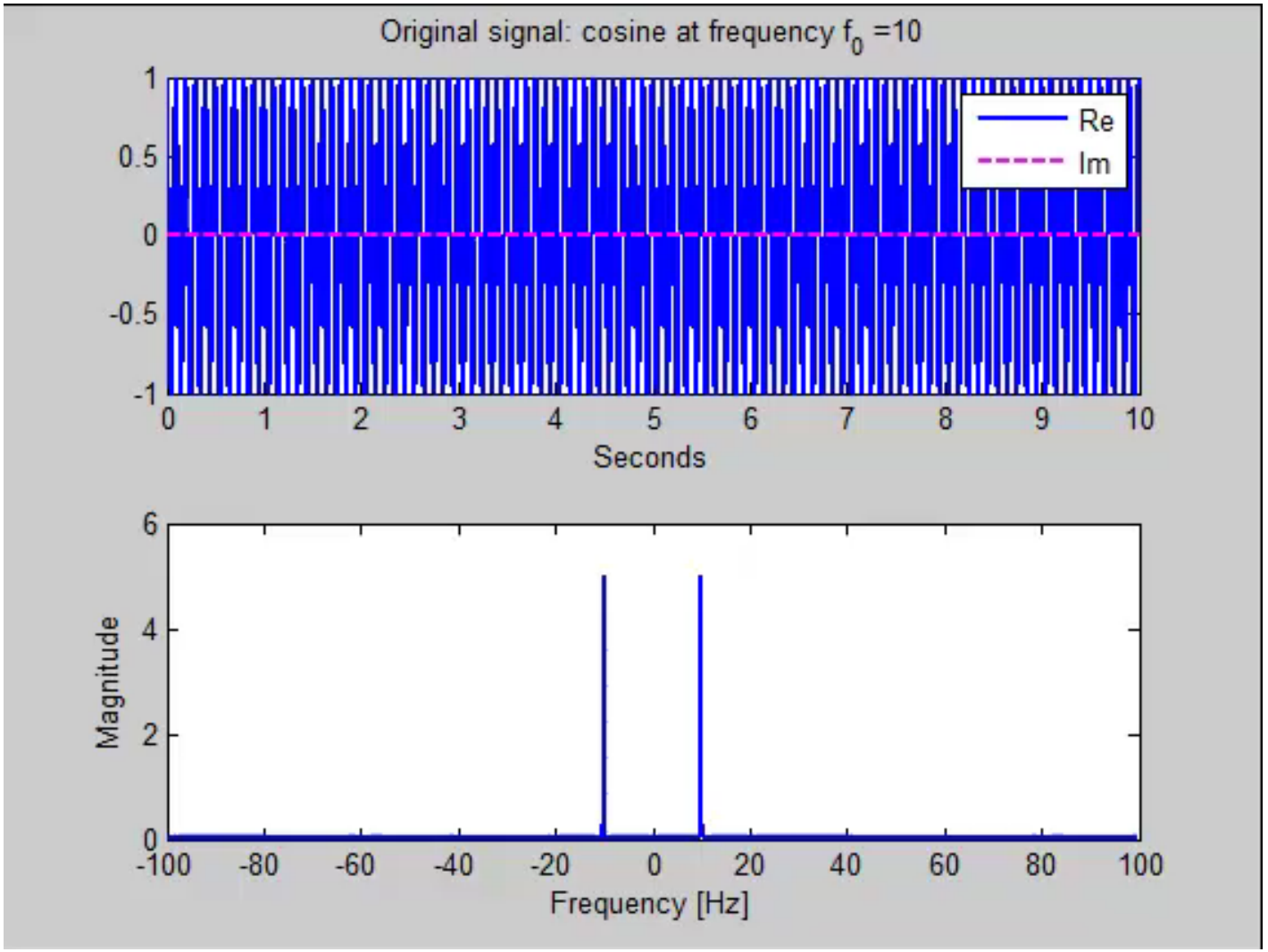


$\cos(2\pi(f_0)t)$

The frequency f_0 of the cosine will be increased (in steps of 10) from 10 Hz to 300 Hz.

[aliasingCos.m]

MATLAB Demo

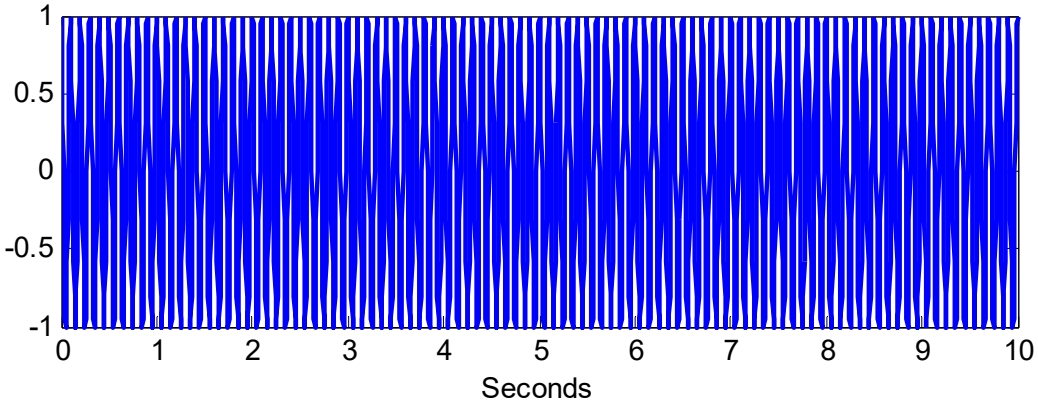


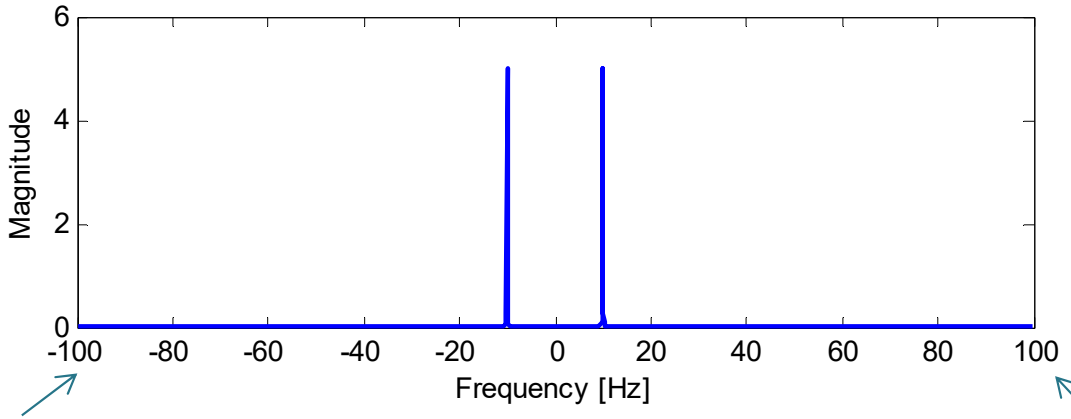
[aliasingCos.m]

Using plotspect.m to study aliasing

- f_s: Sampling frequency $= 200$ samples/sec

$\cos(2\pi(10)t)$





$-\frac{f_s}{2}$ $\frac{f_s}{2}$

In the subsequent plots, we will show only the frequency-domain part.

Figure 46

Using plotspect.m to study aliasing

- f_s: Sampling frequency = 200 samples/sec

$\cos(2\pi(50)t)$

$\cos(2\pi(70)t)$

$\cos(2\pi(100)t)$

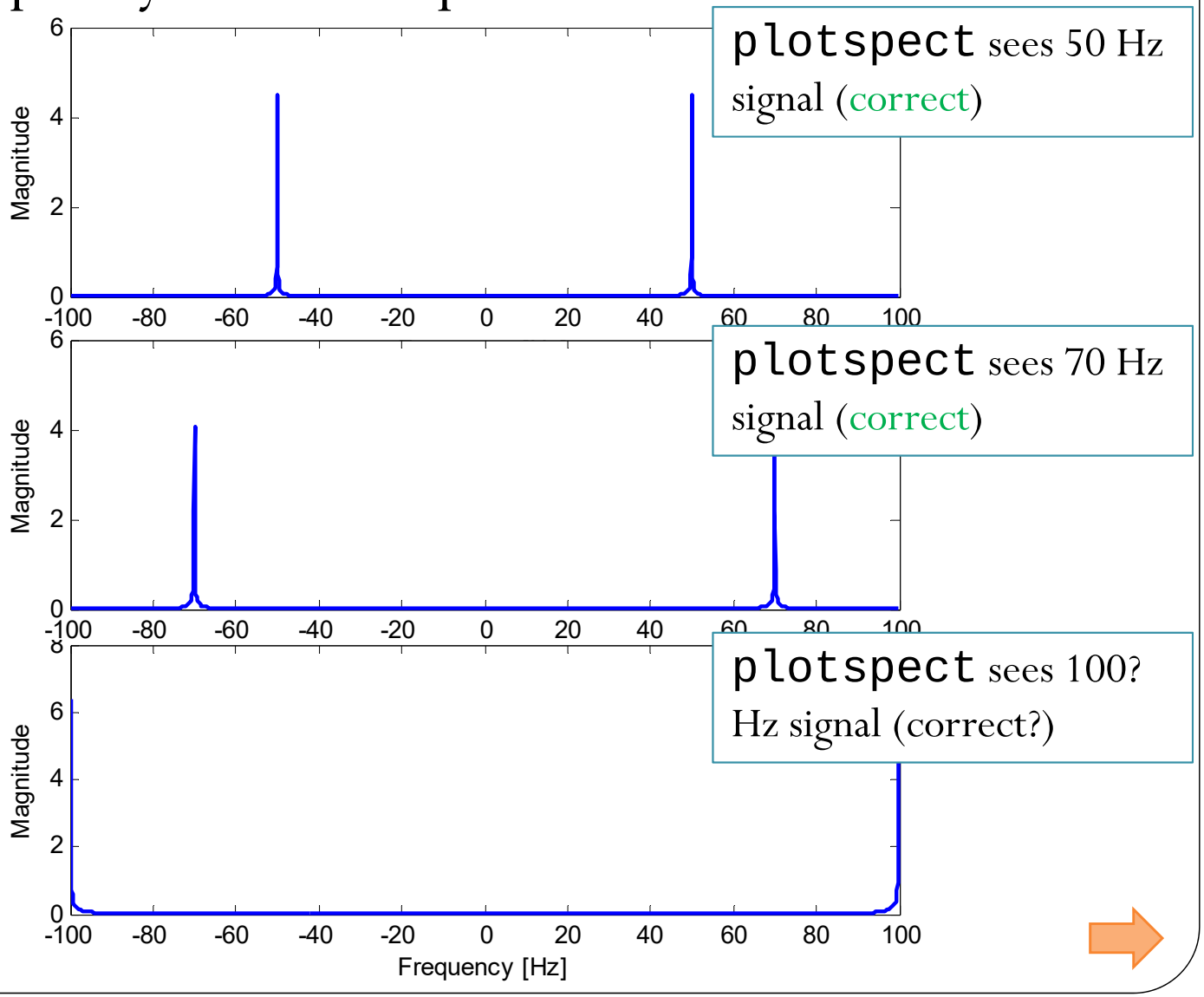
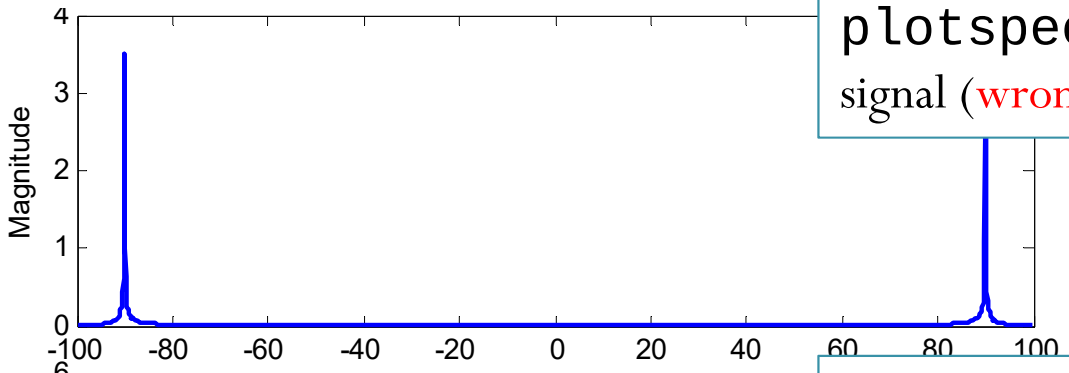


Figure 46

Using plotspect.m to study aliasing

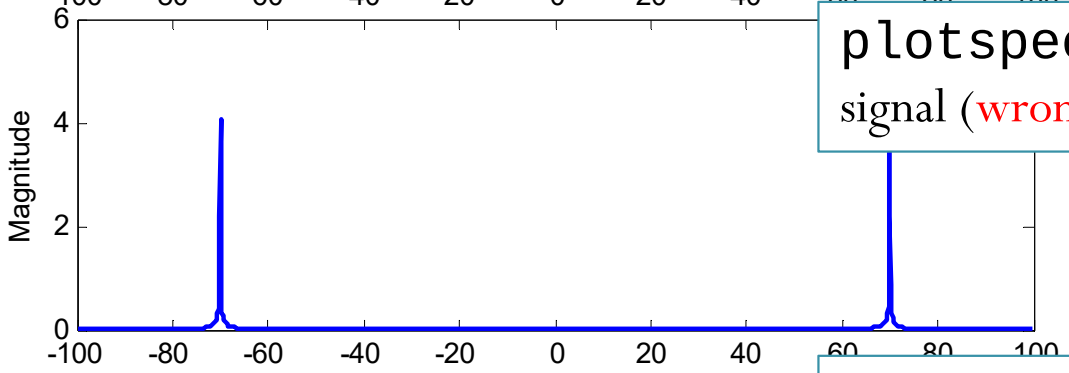
- f_s: Sampling frequency = 200 samples/sec

$\cos(2\pi(110)t)$



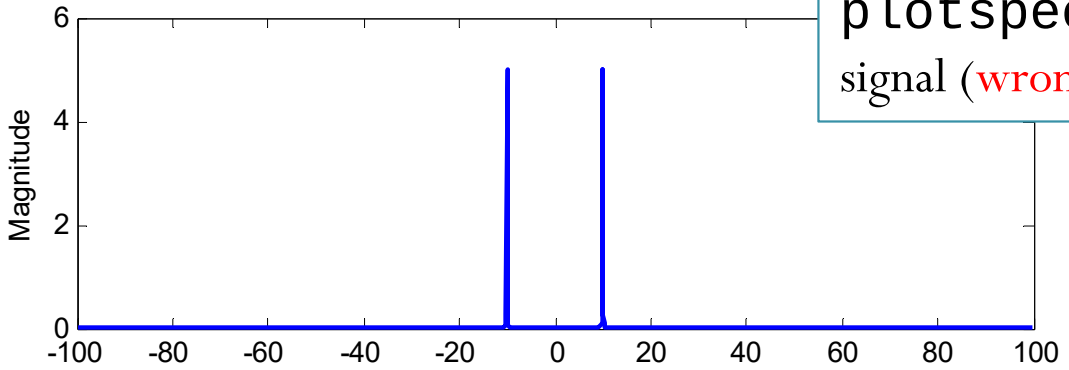
`plotspect` sees 90 Hz signal (wrong!)

$\cos(2\pi(130)t)$



`plotspect` sees 70 Hz signal (wrong!)

$\cos(2\pi(190)t)$



`plotspect` sees 10 Hz signal (wrong!)

Figure 46

Using plotspect.m to study aliasing

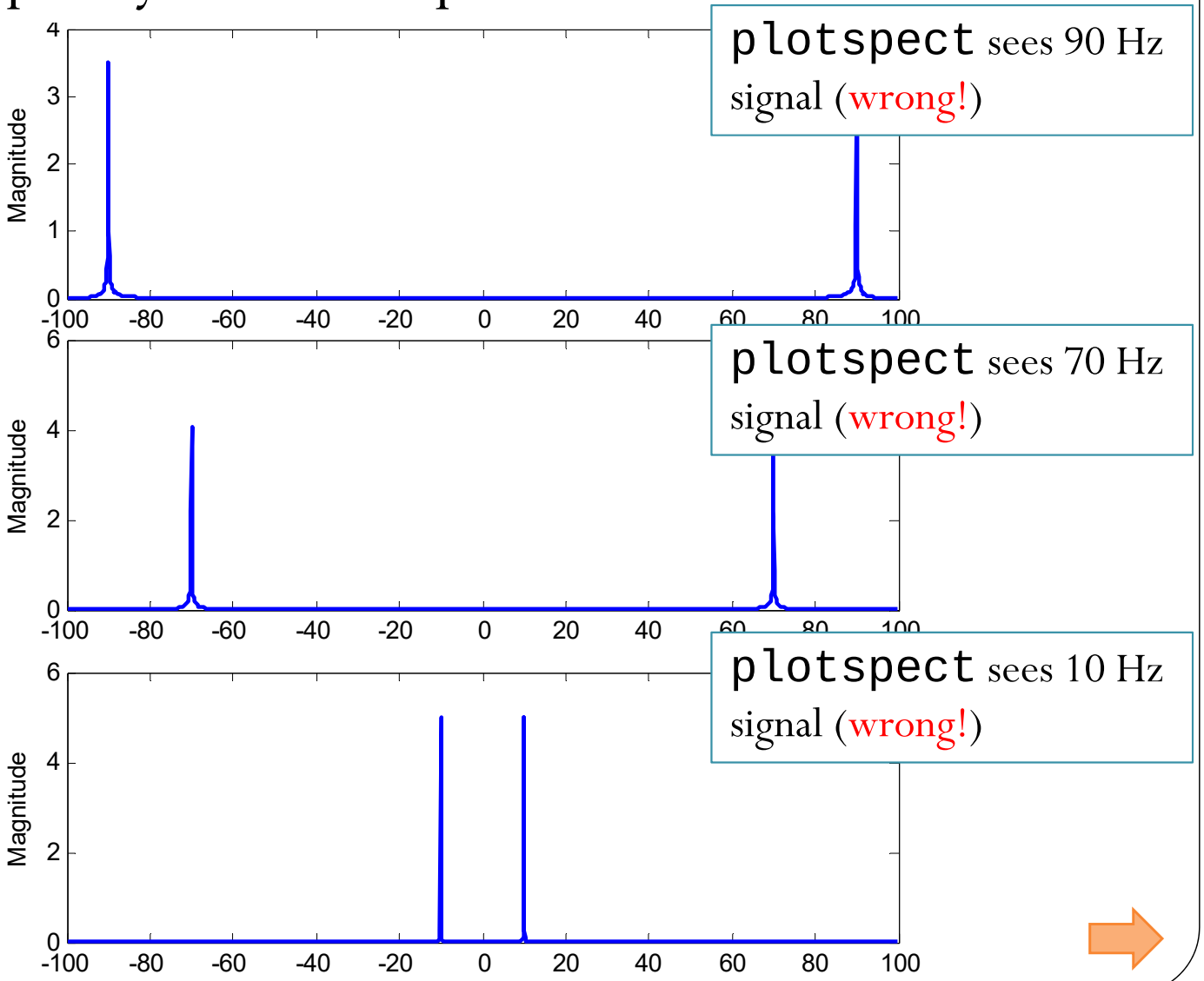
- f_s: Sampling frequency = 200 samples/sec

$\cos(2\pi(110)t)$

This behavior is commonly referred to as **folding**.

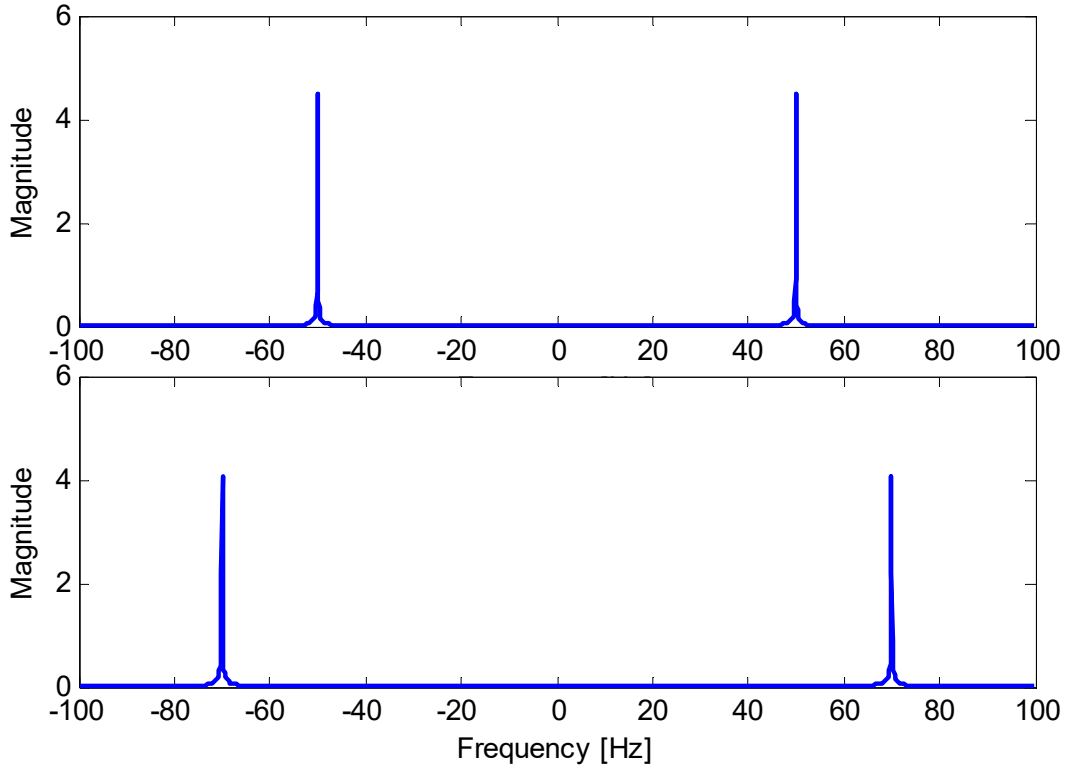
$\cos(2\pi(130)t)$

$\cos(2\pi(190)t)$

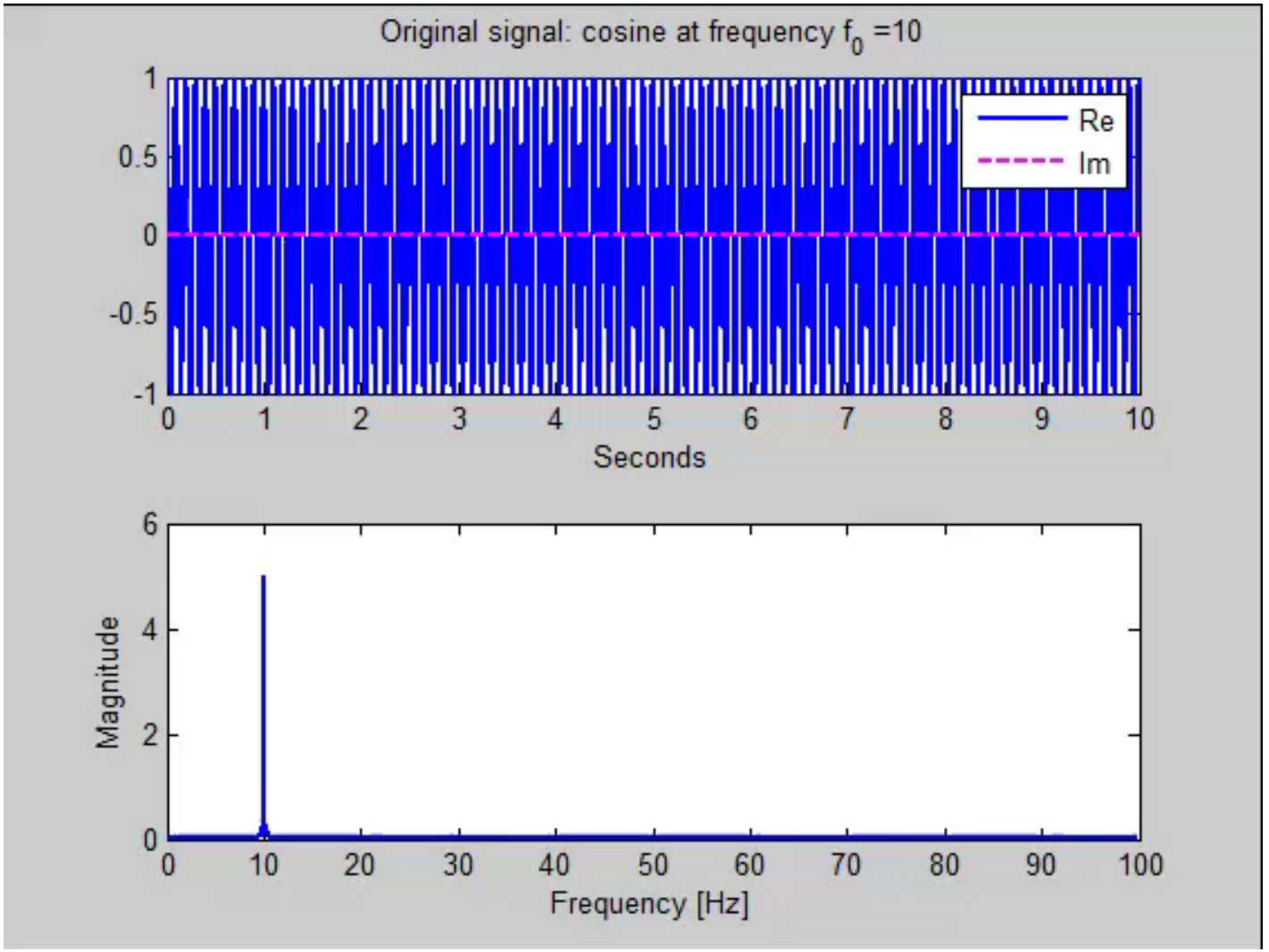


The folding technique

- The even symmetry of the $\cos(2\pi(f_0)t)$ spectrum means that we only have to look at positive frequency to find its perceived frequency



The folding technique

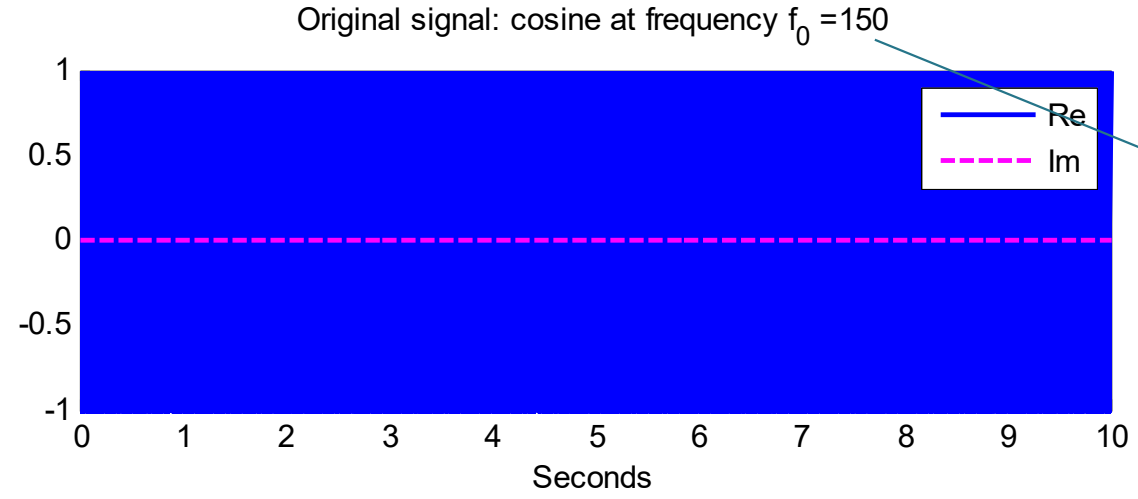


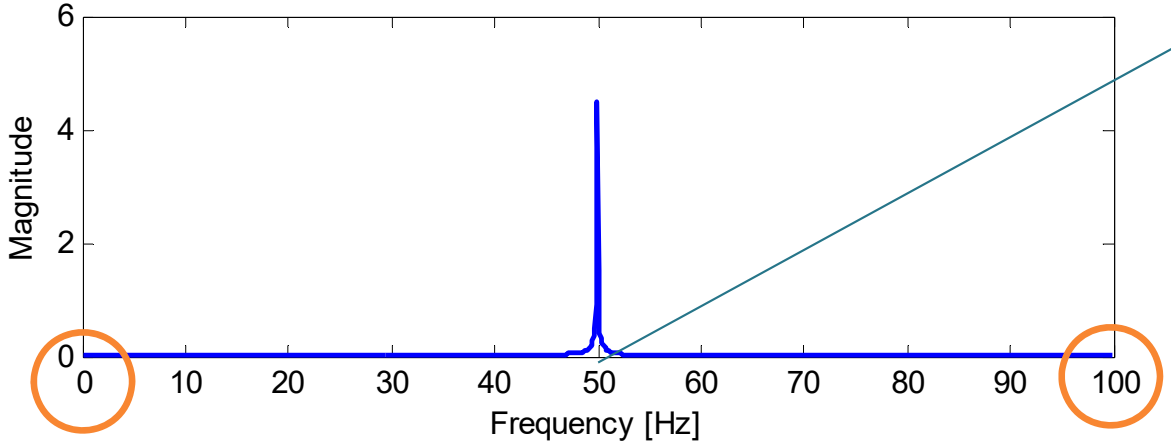
[aliasingCos_folding]

The folding technique

- The folding technique is useful for finding the perceived frequency of $\cos(2\pi(f_0)t)$.

Demo: [aliasingCos_folding]





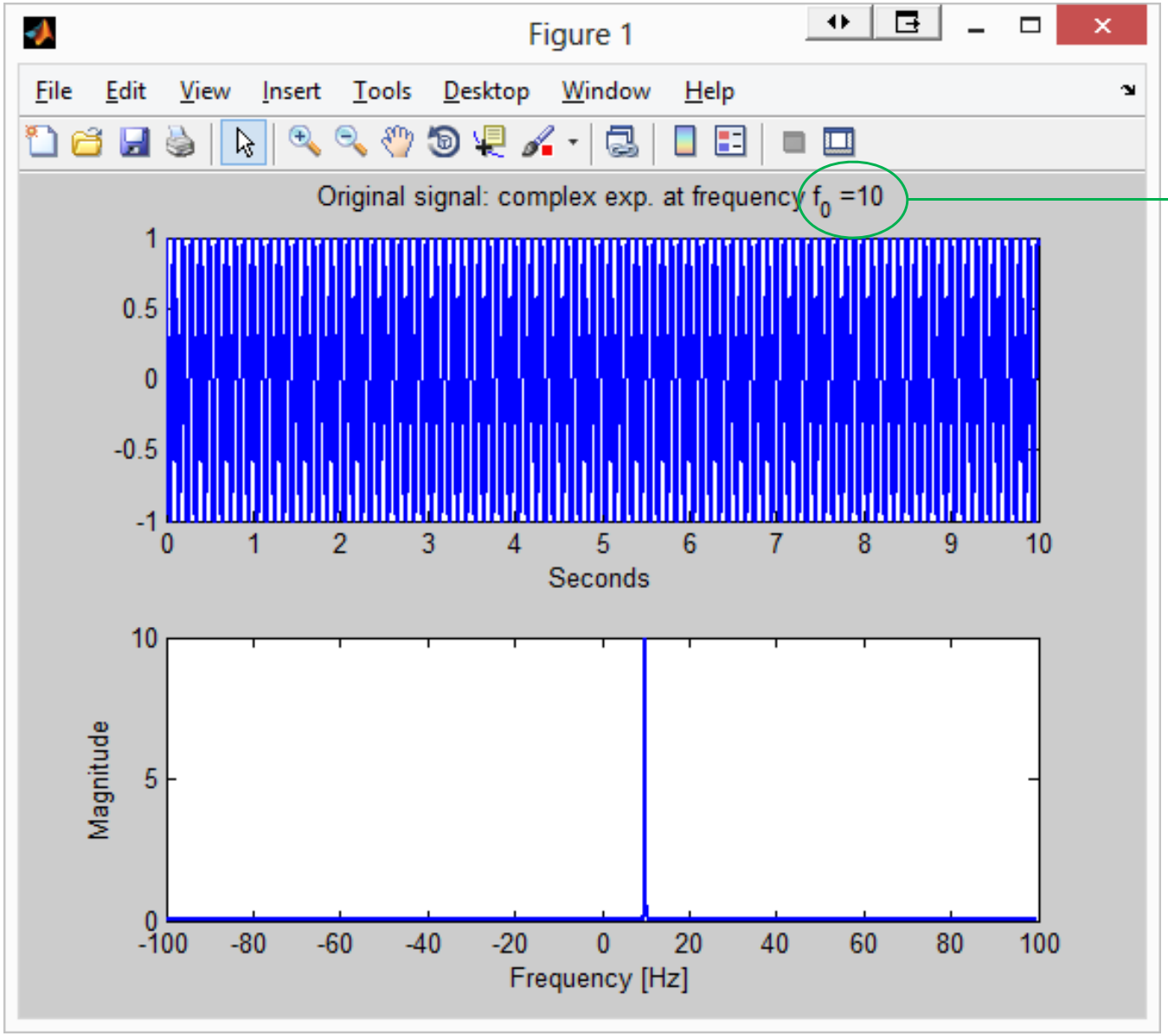
When $f_s = 200$ [Sa/s], the cosine @ freq. 150 Hz will be perceived as a cosine @ freq. 50 Hz.

Pac Man's Tunneling

Actually, the delta functions are doing **tunneling** (like in Pac Man).

MATLAB Demo

f_s: Sampling frequency = 200 samples/sec

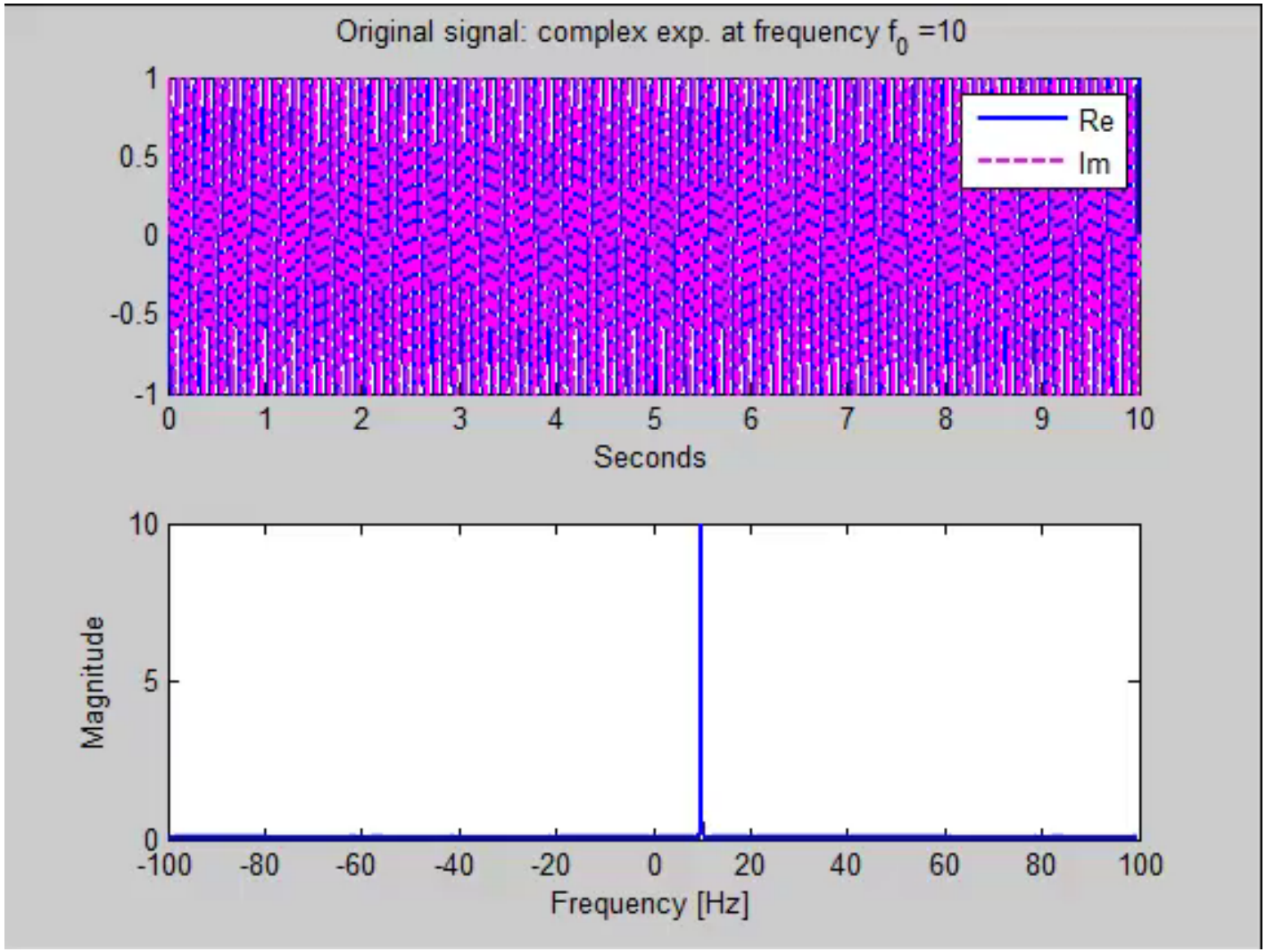


$e^{j2\pi(f_0)t}$

The frequency f_0 of the complex expo. signal is increased (in steps of 10) from 10 Hz to 300 Hz.

[aliasingExp.m]

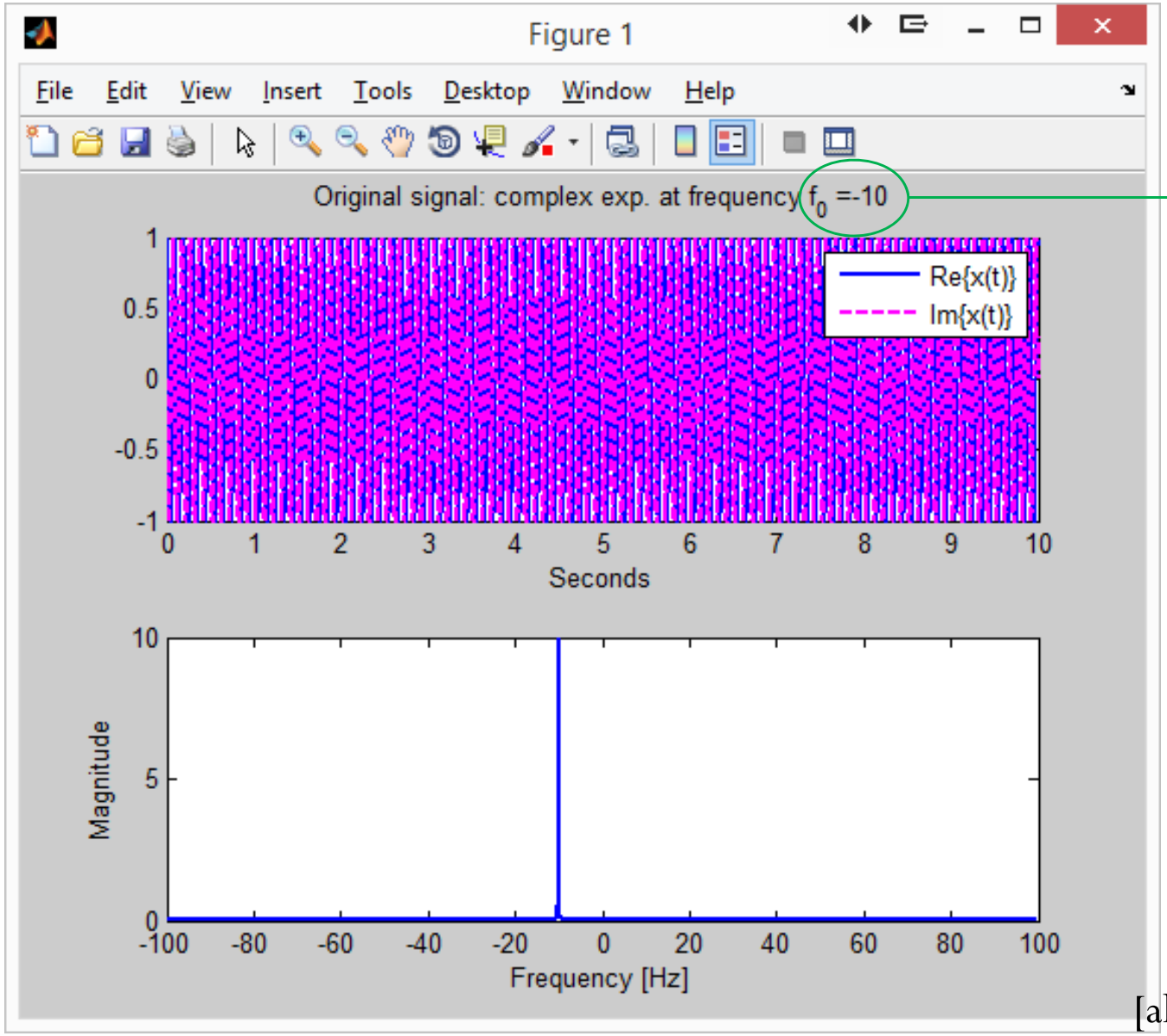
MATLAB Demo



[aliasingExp.m]

MATLAB Demo

f_s: Sampling frequency = 200 samples/sec

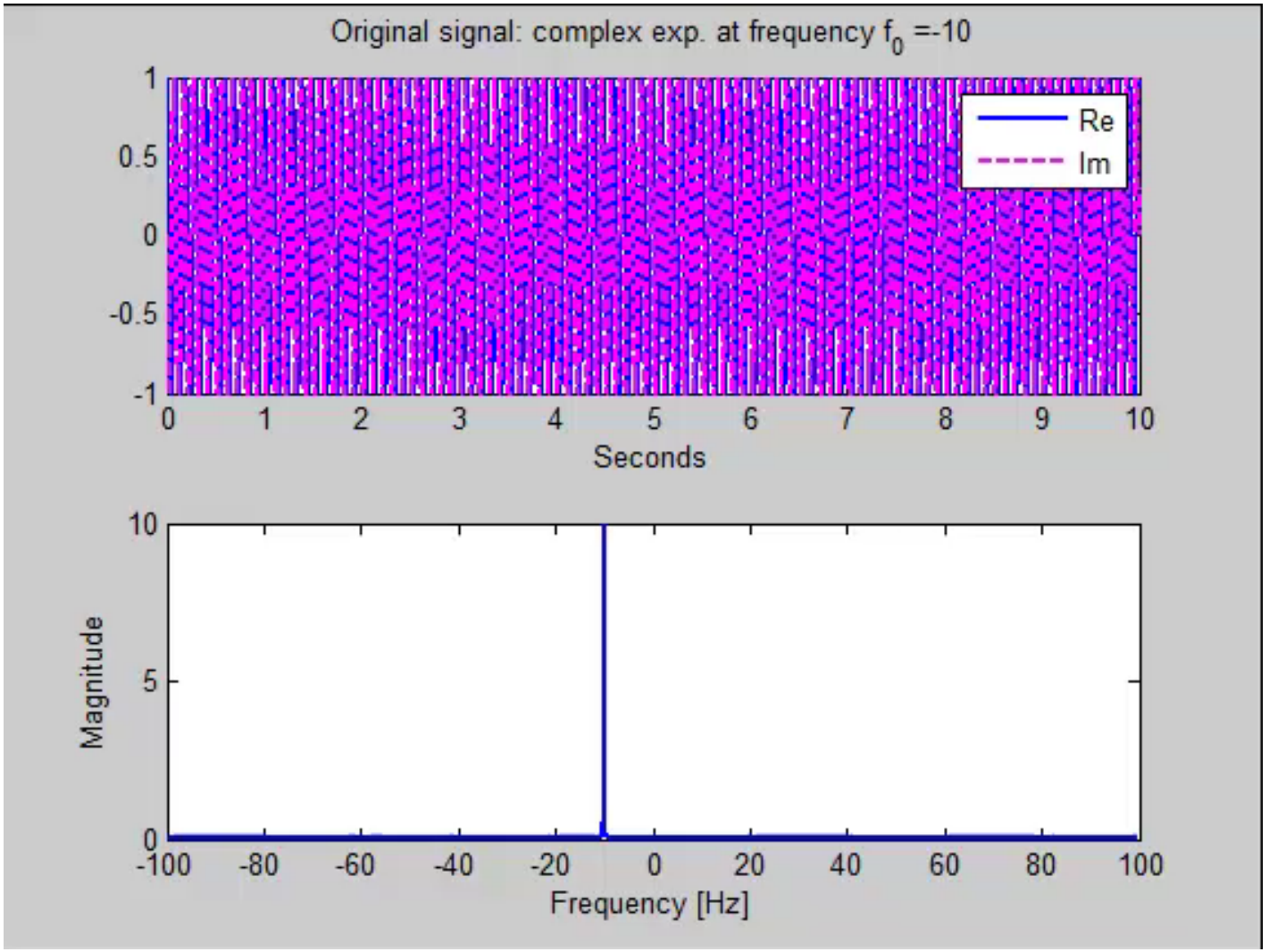


$e^{j2\pi(f_0)t}$

The frequency f_0 of the **complex expo. signal** will be decreased (in steps of 10) from **-10 Hz to -300 Hz.**

[aliasingExpNegative.m]

MATLAB Demo



[aliasingExpNegative.m]

Helicopter Blades Can Look Strange On Video

Video as Succession of Still Images

Frame Rate

Why car wheels rotate backwards in movies?

https://www.youtube.com/watch?v=SFbINinFsxk

Now You See Me 2 Rain Scene

[https://www.youtube.com/watch?v=7qr1lQgK8PI]

Sampling via the Camera

[https://www.youtube.com/watch?v=GBtHeR-hY9Y]

Sampling via the Camera

[https://www.youtube.com/watch?v=GBtHeR-hY9Y]

Sampling via the Camera

[https://www.youtube.com/watch?v=GBtHeR-hY9Y]

Sampling via the Camera

[https://www.youtube.com/watch?v=GBtHeR-hY9Y]

Sampling via Strobe Light

[https://www.youtube.com/watch?v=TH1mJpOnxDE]

Sampling via Strobe Light

[https://www.youtube.com/watch?v=TH1mJpOnxDE]

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[https://www.youtube.com/watch?v=TH1mJpOnxDE]