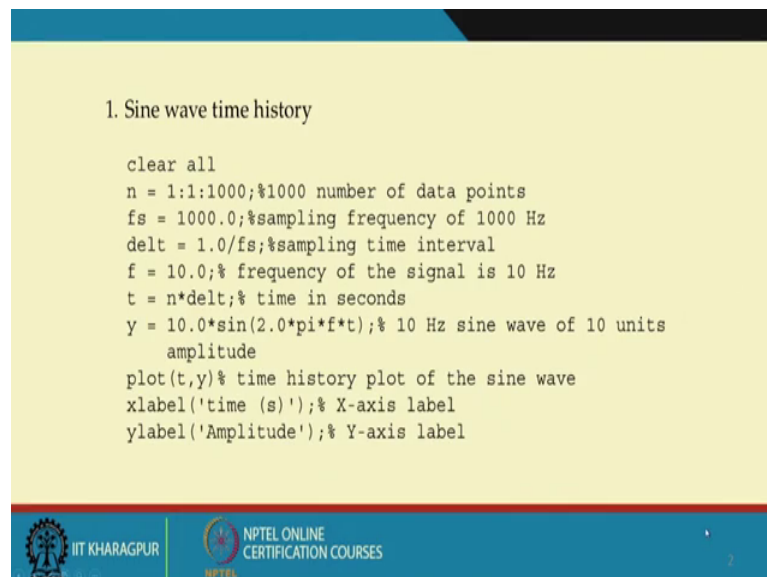


Machinery Fault Diagnosis and Signal Processing
Prof. A. R. Mohanty
Department of Mechanical Engineering
Indian Institute of Technology Kharagpur

Lecture – 22
Signal Processing using MATLAB

Well in this lecture, there go through certain signal processing examples using MATLAB. Like in the previous class you would have just seen an introduction to MATLAB; MATLAB, is a very popular software amongst students in the universities and those of you who are from the industry may not have ready access to MATLAB. But then you could also do the same logic in excel, and well we will the idea behind this lecture is to help you understand some of the signal processing processes or techniques which we have discussed and we will do them as we go in MATLAB. So, that you can feel of how the signals are generated and what kind of analysis is been done particularly to find out their frequencies and so on.

(Refer Slide Time: 01:08)

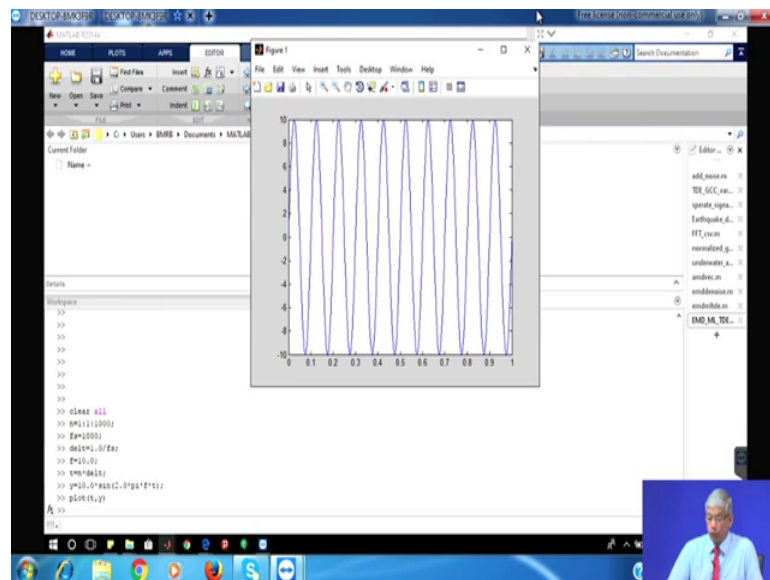


So, the very first example in MATLAB is just doing a sine wave time history I will explain you this, and then we will go through this in MATLAB. So, basically what I have done I have generated an index from 1 to 1000 that is the time steps, I am sampling the signal at 1000 hertz. So the sampling interval is nothing, but 1 by 1000 that depends

seconds I have a signal of 10 hertz, by the way when you see a colon or a semi colon MATLAB ignores everything after the semicolon.

So, anything in percentage is actually in a comment statement, and such comments are given here for our understanding. So, for at any instance of n the time is given as n times Δt . So, now if I plot y is equal to $10 \sin 2\pi f t$, it will prop or it generate at 10 hertz sine wave of 10 unit amplitude, and will plot it as a sine wave of course, you can give a label x level anything you give within quotes time in seconds similarly y label within quotes the amplitude. So, let me just work it out in MATLAB for you all so n is equal to 1 I leave a actually very good idea is to always clear everything before you do MATLAB.

(Refer Slide Time: 02:56)



So, n is equal to 1 to my sampling frequency f_s is 1 by 1000, i is 1000, so Δt is nothing but 1 divided by 1000 (Refer Time: 03:15) first I will have a sine wave frequency of f is equal to 10, and then time at any instance t is $n \times \Delta t$ I will plot y is equal to $10 \sin 2\pi f t$ and before the execute this operation you would see that all the variables are already defined like π is already defined in MATLAB, f is given t has been calculated and so on.

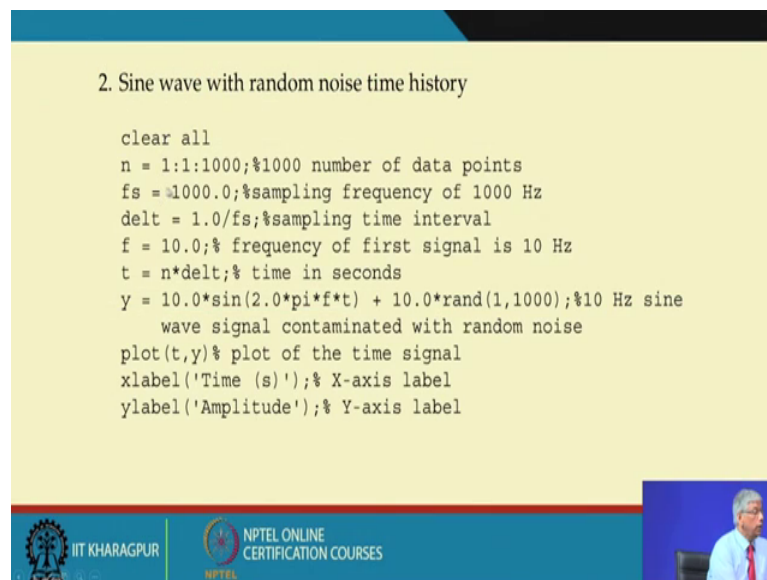
So, now I can plot see this I have generated a sine wave for a total duration of 1 seconds, now why is this 1 all of you those who have done signal processing will know that, since my I do not see the cursor coming in here, but let me come here. Then see I have

generated an index till 1000 sampling frequency at 1000. So, my total time when Δt is 1 by 1000 and n is 1000 the maximum value is 1 second, and my sine wave is of 10 hertz frequency.

So, the time period is 0.21 so, within a time of once second I would see 10 complete waveforms of the sine wave and that is what I see in this plot here, you can see this oh move markers are here this is a 10 complete waveforms I will see here on the MATLAB screen. So, this is 1 example which we did ok.

Now, let me quit let me clear so, nothing is that I can always do a whose to see that nothing is there remember it is clear no algorithm.

(Refer Slide Time: 06:09)



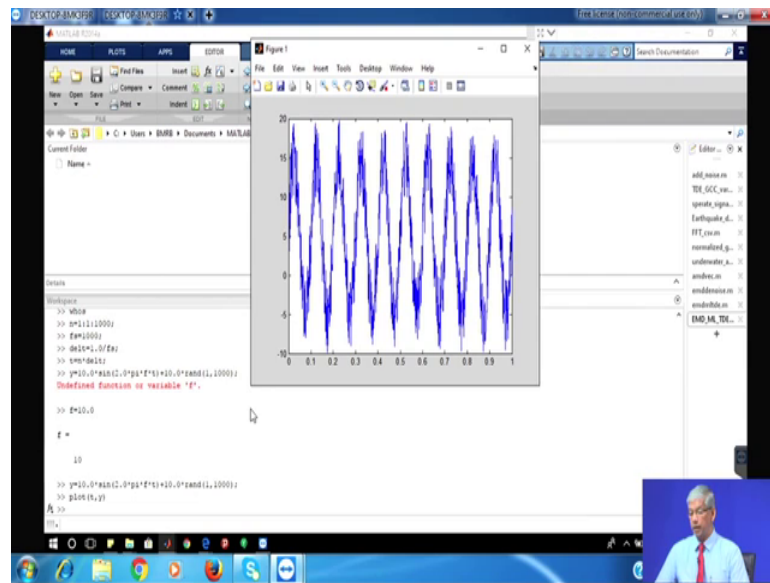
2. Sine wave with random noise time history

```
clear all
n = 1:1:1000;%1000 number of data points
fs = 1000.0;%sampling frequency of 1000 Hz
delt = 1.0/fs;%sampling time interval
f = 10.0;% frequency of first signal is 10 Hz
t = n*delt;% time in seconds
y = 10.0*sin(2.0*pi*f*t) + 10.0*rand(1,1000);%10 Hz sine
    wave signal contaminated with random noise
plot(t,y)% plot of the time signal
xlabel('Time (s)');% X-axis label
ylabel('Amplitude');% Y-axis label
```

The slide displays MATLAB code for generating a sine wave with random noise. The code includes comments for each step: clearing the workspace, defining the number of data points (n=1000), sampling frequency (fs=1000 Hz), sampling time interval (delt=1/fs), signal frequency (f=10 Hz), time vector (t), and the signal equation (y = 10.0*sin(2.0*pi*f*t) + 10.0*rand(1,1000)). It also includes plotting commands and axis labels. The slide is part of an NPTEL presentation from IIT Kharagpur, featuring a small video inset of the lecturer in the bottom right corner.

Next example a very to the same sine wave I have added a random noise you know everything also same, I have added a random noise. And then I am going to plot the sine wave with her random noise.

(Refer Slide Time: 06:31)




So, let me just quickly go through what we did and is equal to $1/t$ is equal to n times Δt , and then I will add y is equal to $10.0 \sin 2.0 \pi f t$ and to this I am adding the random noise of this amplitude $10.0 \sin$ and yeah I have not defined f here.

So, I will make this f as a so what I could do is you know I have by typing are mixed the expression f . So, I will give f is equal to 10.0 , and then execute this command. So, you see because while typing and miss f it was not able to compute this expression. So, once I given the value f and recomputed it has taken under value. So, now, I can plot you see earlier I had a very neat sine wave, but now to the sine wave a random noise has been added. So, you can see in MATLAB in fact many of the real signals which you will see will be having such signals.


(Refer Slide Time: 08:44)

3. Square wave-generated time signal


```
clear all
[u,t] = gensig('square',0.1,1,0.001);% 10 Hz square wave
      for 1 second duration sampled at 1000 Hz
ua = 10.0*u;%square wave of 10 units amplitude
plot(t,ua)% plot of the 10 Hz square wave time signal
xlabel('Time (s)');% X-axis label
ylabel('Amplitude');% Y-axis label
```



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Now, this let us go to another command or another program. Wherein I am generating a square wave by given this expression gentie, were in I am generating a square wave for 1 second duration sample that 1000 hertz and 0.1 you know leaving the due to cycle, and then u a is equal to 10. So, you can always do help gensig just to be clear am I clear all here generate signal.

(Refer Slide Time: 09:40)

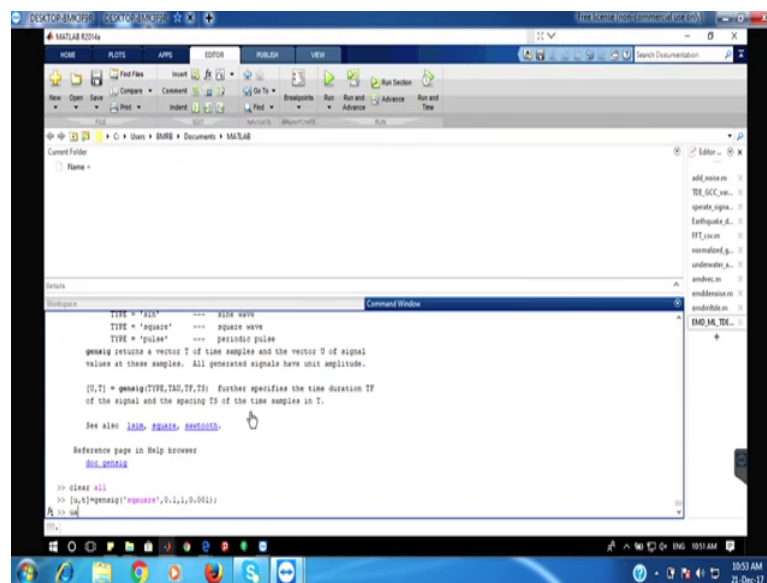
```
clear all
T=1;
f=10;
[u,t]=gensig('square',T,f,1/1000);
plot(t,u);
xlabel('Time (s)');
ylabel('Amplitude');
title('10 Hz Square Wave');
hold on;
plot(t,u*10);
xlabel('Time (s)');
ylabel('Amplitude');
title('10 Hz Square Wave with Amplitude 10');
hold off;
```

```
clear all
T=1;
f=10;
[u,t]=gensig('square',T,f,1/1000);
plot(t,u);
xlabel('Time (s)');
ylabel('Amplitude');
title('10 Hz Square Wave');
hold on;
plot(t,u*10);
xlabel('Time (s)');
ylabel('Amplitude');
title('10 Hz Square Wave with Amplitude 10');
hold off;
```



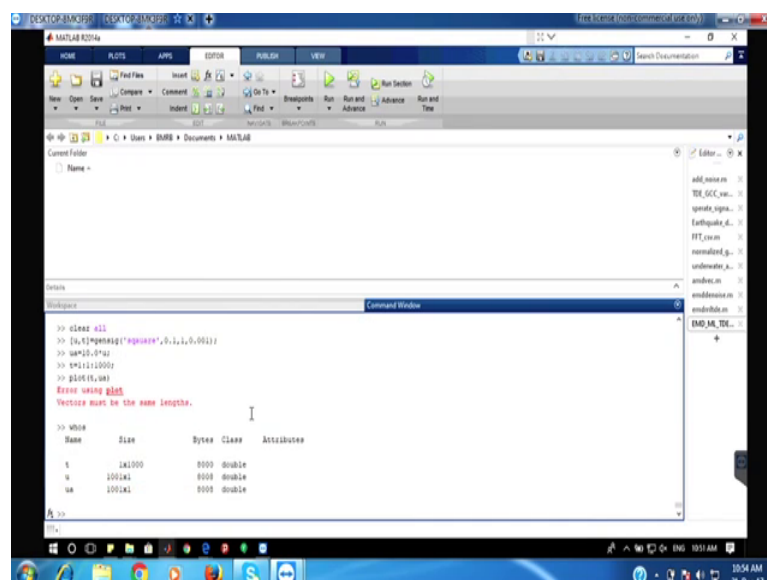
So, general signal type you can generate tau scalar signal u f signal type and period tau ok.

(Refer Slide Time: 09:50)



So, u t for the time duration of the signal spacing t s at the time samples in t seconds. So, let us do it like this clear all second back at u comma t is equal to gensig square 0.1, 1, 0.01 now I am amplifying the danube by a unit of 10 on our plot, because I have to generate t is equal to 1. So, plot t (Refer Time: 11:16) here, then I can always do a debugging online whose u a ok.

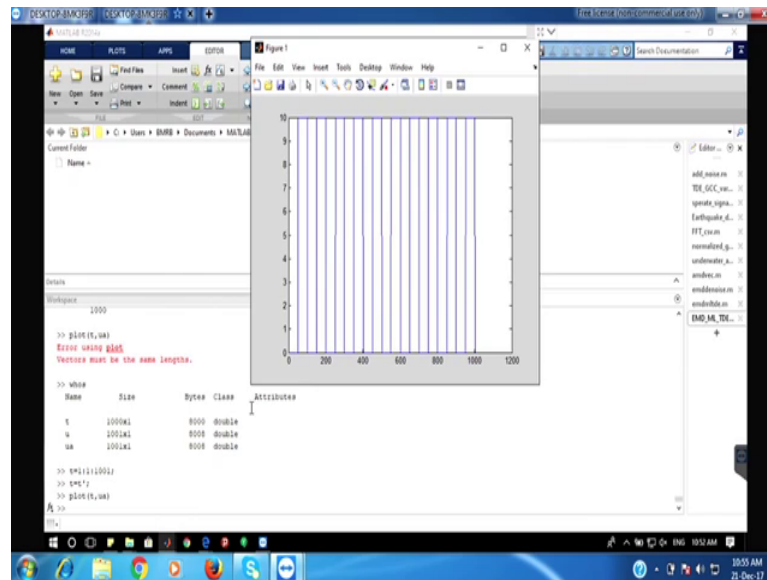
(Refer Slide Time: 11:26)



I can generate this t is equal to t transpose plot I mean (Refer Time: 12:01) 1000 1 let me t is equal to 1 plot sorry t is equal to e transpose plot t u a see. I have generated a square

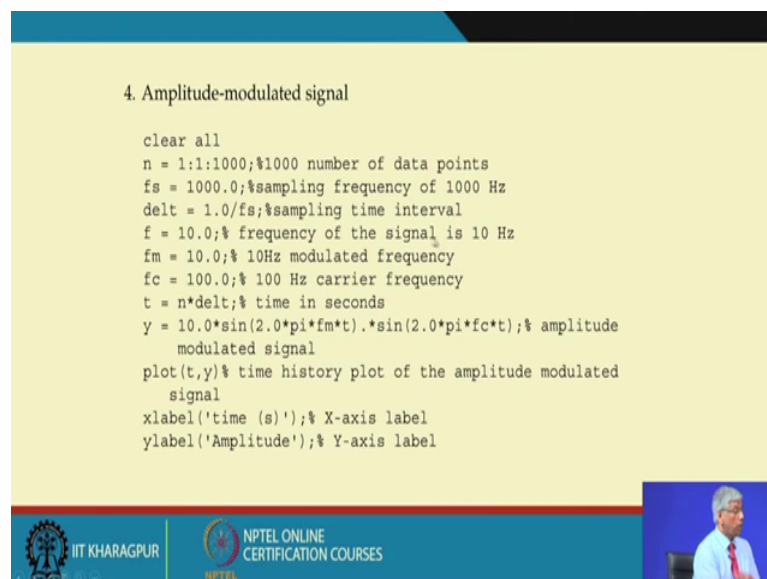
wave and there was an error because you know I could quickly debug it you know for some reason u a is 1000 1 points, and gen initially are generated a 1000 points that is why I get this error fetes must be the same length.

(Refer Slide Time: 12:32)



So, what I did is I increase t from 1 colon 1 to 1001, and then made a transpose and I plotted so, I have generated a square wave. I will now go to the next example of clear all.

(Refer Slide Time: 13:06)

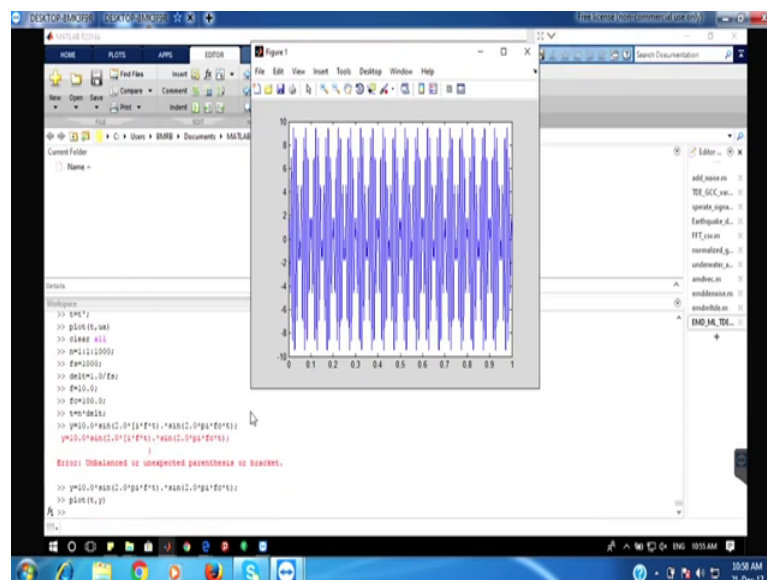


So, I am now generating an amplitude modulated waveform. If you all are not familiar with the end sampling frequency delta t frequency of the signal is 10 hertz. So, frequency

modulated frequency is 10 hertz, and the carrier frequency is 100 hertz. So, I am generating a modulated sine wave, and let us see how it looks like so quickly if I copy whatever is given here. So, n is equal to 1 2000 f s is equal to 1000 delta t is nothing, but 1.0 by f s, f is equal to 10.0 the modulated frequency, f c is 100.0 the carrier frequency, t is equal to n star del t, and then I will generate y is equal to 10.0 star sin 2.0 star pi star f star t. And you see this dot star sine 2.0 star pi star pi star fc star t, I did a typo here I can see here you should not do in the second bracket. So, I can correct it by pi this what I have been pi ok.

So, you can see in real time you can do such corrections. So, my amplitude modulated signal is there so, I can now plot t and y.

(Refer Slide Time: 15:21)




So, you can see modulations of the amplitude occurring. And there is an increasing decreasing again increasing and so on. So, within a period of 1 seconds I have got the time, once again total time it is a 10 hertz sine wave which is getting modulated by a carrier frequency of 100 hertz is how this is going to look like.


(Refer Slide Time: 15:50)

5. Frequency-modulated signal


```
clear all
n = 1:1:1000;%1000 number of data points
fs = 1000.0;%sampling frequency of 1000 Hz
delt = 1.0/fs;%sampling time interval
f = 10.0;% frequency of the signal is 10 Hz
fm = 10.0;% 10Hz modulated frequency
fc = 100.0;% 100 Hz carrier frequency
t = n*delt;% time in seconds
y = 10.0*sin(2.0*pi*fm*t+(sin(2.0*pi*fc*t)));% frequency
modulated signal
plot(t,y)% time history plot of the frequency modulated
signal
xlabel('time (s)');% X-axis label
ylabel('Amplitude');% Y-axis label
```



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Now, I will go to the next example similarly for the frequency modulated signal I will not do this in at MATLAB here, but you can see the same sequence have been followed only thing is that when I have the frequency modulation expressions. Similarly I have to change the frequency contained by this expression, and this could be 1 of your home worlds to plot a frequency modulated signal in MATLAB.


(Refer Slide Time: 16:18)

6. Beat signal


```
clear all
n = 1:1:10000;%10000 number of data points
fs = 1000.0;%sampling frequency of 1000 Hz
delt = 1.0/fs;%sampling time interval
f1 = 10.0;% frequency of first signal is 10 Hz
f2 = 11.0;% frequency of second signal is 11 Hz
t = n*delt;% time in seconds
y = 10.0*sin(2.0*pi*f1*t)+10.0*sin(2.0*pi*f2*t);%beat
signal
plot(t,y)% time history plot of the beat signal
xlabel('time (s)');% X-axis label
ylabel('Amplitude');% Y-axis label
```



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Similarly, I can generate a bits signal wherein I can we will see these bits of the signal, when we do the case of heterodyning where I have 10000 points. The only catch in bits

signal is the frequencies f_1 and f_2 are very close to each other, f_1 is 10 hertz and others 11 hertz. And I am just adding 2 signals one being 10 hertz, another being 11 hertz. They will look something very close to an amplitude modulated signal, but they are not amplitude modulated in that sense.


(Refer Slide Time: 16:58)

7. Fast Fourier transform (FFT) of a signal


```
clear all
n = 1:1:1000;%1000 number of data points
fs = 1000.0;%sampling frequency of 1000 Hz
delt = 1.0/fs;%sampling time interval
f = 77.0;% frequency of first signal is 77 Hz
t = n*delt;% time in seconds
Totaltime = 1000*delt;%length of the time signal
y = 10.0*sin(2.0*pi*f*t);%77 Hz sine wave signal
yfft = 2.0/1000.0*fft(y);% complex FFT of 77 Hz sine wave
signal
yabs = abs(yfft);%magnitude of the FFT
delf = 1.0/Totaltime;% frequency resolution
n2 = 1:1:500;%FFT results are plotted till N/2 data points
fk = delf.*n2;%frequency values
plot(fk,yabs(1:500))% spectrum of the time signal
xlabel('Frequency (Hz)');% X-axis label
ylabel('Amplitude');% Y-axis label
```



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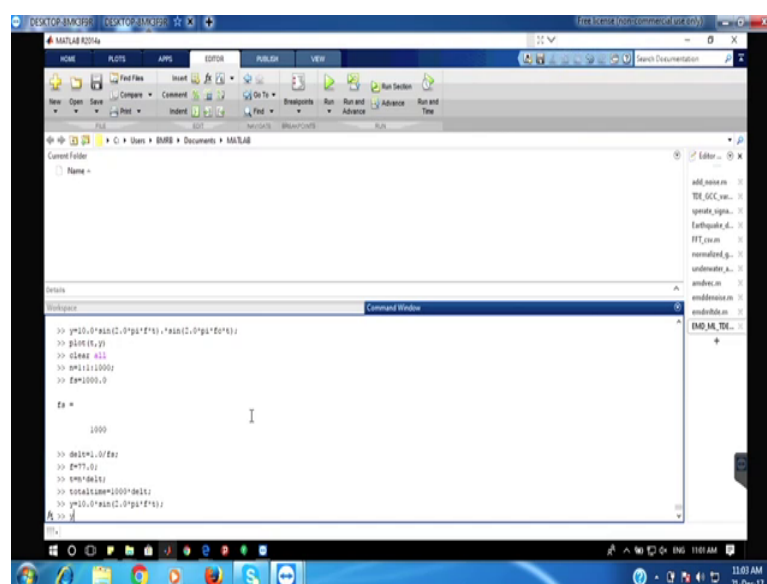


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Now, I will come to 1 of the very important examples as in how do I do Fourier transform of a signal ok.

(Refer Slide Time: 17:17)



The image shows the MATLAB R2014a interface. The Command Window displays the following code:

```
>> y=20.0*sin(2.0*pi*f*t)+sin(2.0*pi*f*t);
>> plot(t,y);
>> clear all
>> N=1:1:1000;
>> Fs=1000.0;

Fs =

    1000

>> delt=1./Fs;
>> t=0:delt:1;
>> N=length(t);
>> y=20.0*sin(2.0*pi*f*t)+sin(2.0*pi*f*t);
>>
```

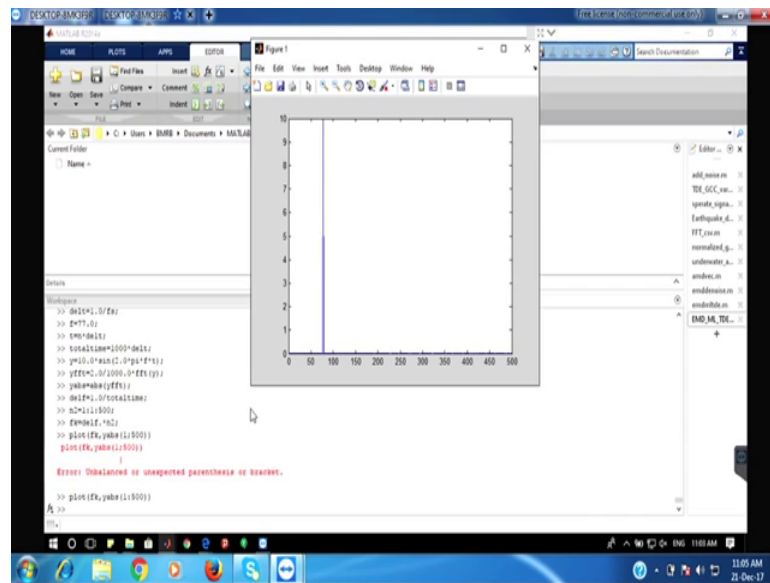
So, let us see this example here so, before I let me explain you what this is you all are not familiar with this index n is equal to 1 to 1000 sampling frequency is 1000 hertz. So, Δt is the sampling interval is nothing, but 1 by sampling frequency I have a frequency of 77 hertz, and total time of the signal is 1000 times Δt .

So, I have generated my sine wave time signal of 77 hertz by this expression y is equal to $10 \cdot \sin(2 \pi f t)$, and this is the most important command here. Wherein I am doing the complex FFT of this 77 hertz sine wave signal. Wherein you see this is a scaling factor which we use to get the right amplitudes this is 2 divided by the number of data points, in our case the data points being 1000 I will multiply the scaling factor with the FFT, but as you know once we convert a signal from time domain to frequency domain it becomes a complex quantity.

So, why FFT is actually a complex quantity which I will just calculate and show you, and then to find out the magnitude I just do the y apps of the magnitude absolute value of the complex values of FFT. And the delta frequency in the frequency resolution in the frequency domain is 1 by total time; total time is given by this expression in it, and since the FFT results are plotted till and by 2 because of the negative frequency.

So, I am plotting from 1 by 5000 . So, I can plot at any frequency till n by 2 the Δf and I will (Refer Time: 19:17). Let us work this example out for everybody's benefit. So, n is equal to 1 colon 1 , 1000 then I have f_s is 1000 see did because I did not give the colon semicolon it did not prompt the Δt is nothing, but 1 divided by f_s f is 77 hertz out of the frequency of my sine wave total time is nothing, but n times Δt an instance t total time yes 1000 times Δt . So, y is equal to $10.0 \cdot \sin(2.0 \cdot y \cdot f \cdot d)$ they are all been defined beforehand.

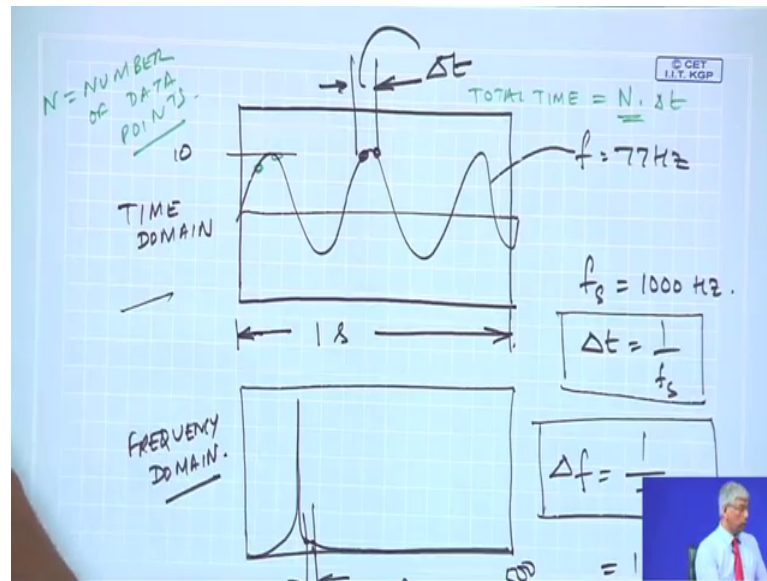
(Refer Slide Time: 20:46)



So, now I do the FFT y FFT is equal to this is very important you may not find them in the MATLAB handouts 50 y. So, the absolute value y apps was nothing, but a f t, and then I will plot the del f del f is nothing, but 1.0 divided by total time. And then in 2 is nothing, but a new index till the 500 points just to plot the first half frequency at any instance of n 2 is nothing, but this times sorry is equal to del f times into so, now I will plot fk and y apps the first 500 I made a mistake here.

This should have been colon instead of a semicolon. So, I will correct it by putting a semicolon it is good to do such mistakes so, that you get to phi. Now this is the frequency spectrum of the signal this is in frequency domain I had sampled at 1000 hertz. So, this is till 500 hertz and my magnitude is 10 hertz and this is close to 77. So, let me explain you what how we did FFT and what are the time block.

(Refer Slide Time: 22:57)




So, to begin with I generated a sine wave of amplitude 10 this are frequency is 77 hertz, where my sampling frequency was 1000 hertz. So, delta t is nothing, but $1/f_s$ so, at every 2 points this is my delta t. And this I took for n is equal to 1000 and this was only for total time was 1 second. Now once I went to FFT I plotted till 500 hertz, and the spacing just was this is here delta f. So, delta f is nothing but $1/\text{total time}$.

In this case because this is 1 second our delta f is 1 hertz. So, since the signal was 77 at 77 hertz I see a peak of 10 hertz, and this is what so this is in time domain, and this is in frequency domain. So, the relationship between delta f, and total time is very important and this. And you know how total time is related is the total time there is nothing, but N times delta t where N is the number of data points. Of course I have not talked regarding windowing etcetera no that is for a later course, but you know this is something which we need to understand in terms of the frequency content ok.


(Refer Slide Time: 25:26)

8. Envelope detection


```
clear all
n = 1:1:10000;%10000 number of data points
fs = 1000.0;%sampling frequency of 1000 Hz
delt = 1.0/fs;%sampling time interval
f1 = 10.0;% frequency of first signal is 10 Hz
f2 = 11.0;% frequency of second signal is 11 Hz
t = n*delt;% time in seconds
y = 10.0*sin(2.0*pi*f1*t)+10.0*sin(2.0*pi*f2*t);%beat
    signal
yh = hilbert(y);%hilbert transform to obtain the envelope
    of the time domain signal
yz = abs(yh);% real part of the complex hilbert transform
plot(t,yz)% time history plot of the enveloped signal
xlabel('time (s)');% X-axis label
ylabel('Amplitude');% Y-axis label
```




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Now, I will move to the next. So, you can do an envelope detection because whenever we have the case of amplitude modulated signal so this is an amplitude modulated signal here. So, I will just do an Hilbert transform of this signal, and then absolute value of the Hilbert transform actually gives the envelope of that signal ok.


(Refer Slide Time: 25:56)

9. Time domain features of the signal


```
clear all
n = 1:1:1000;%1000 number of data points
fs = 1000.0;%sampling frequency of 1000 Hz
delt = 1.0/fs;%sampling time interval
f = 10.0;% frequency of the signal is 10 Hz
t = n*delt;% time in seconds
y = 5.0+10.0*sin(2.0*pi*f*t);% 10 Hz sine wave with a dc
    offset of 5
ymax = max(y);% Maximum value of the signal
ymin = min(y);% Minimum value of the signal
ym = mean(y);% Mean value of the signal
yvar = var(y);% Variance of the signal
ystd = std(y);% Standard deviation of the signal
ykurt = kurtosis(y);% Kurtosis of the signal
yskew = skewness(y);% Skewness of the signal
```




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And similarly like I was telling you there are many features in a signal. So, if a signal has been generated is the 5 hertz has been a dc offset added to a signal of 10 hertz, I can find out certain parameters the maximum value minimum value mean variance standard

deviation kurtosis kurtosis these are all built in functions in MATLAB which could be used to calculate these expressions ok.

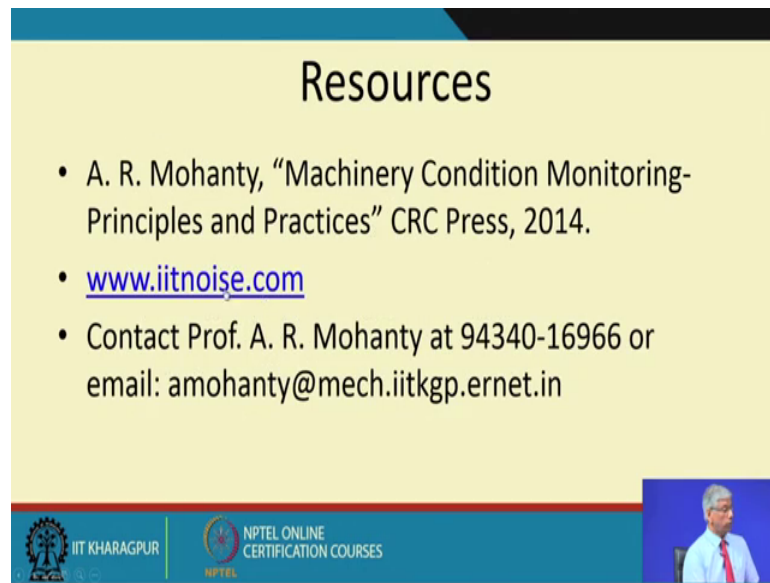
(Refer Slide Time: 26:33)

```
10. Cepstrum analysis

clear all
n = 1:1:1000;%1000 number of data points
fs = 1000.0;%sampling frequency of 1000 Hz
delt = 1.0/fs;%sampling time interval
f = 10.0;% frequency of the signal is 10 Hz
t = n*delt;% time in seconds
y = 10.0*sin(2.0*pi*f*t);% 10 Hz sine wave of 10 units
    amplitude
k = 1:1:1100;% total sample length is for 1.1 seconds
yc = [zeros(1,100) y];%Sine wave delayed by 0.1 seconds
c = cceps(yc);%complex cepstrum
plot(k,c)% cepstrum at quefrecencies of 0.1 second and its
    raharmonics
xlabel('quefrecency (ms)');% X-axis label
ylabel('Amplitude');% Y-axis label
```

And then you will see the actual expressions for this in my book. And similarly another example which you all of you could try is the substances also. So, I have generated the signal have then added certain sample length. And where the sine wave is delayed by 1 second, and then I can see the complex sub strum by this command here and I can plot the cue frames is at point 1 second and its law harmonics. So, this is very important technique of substances complex substance is given by the c steps command.

(Refer Slide Time: 27:22)



The slide is titled "Resources" in a large, bold, black font. Below the title, there is a bulleted list of three items: a book by A. R. Mohanty, a website URL, and contact information for Prof. A. R. Mohanty. The slide has a yellow background with a blue header and footer. The footer contains the IIT Kharagpur logo and the NPTEL Online Certification Courses logo. A small video inset in the bottom right corner shows a man in a white shirt and red tie.

Resources

- A. R. Mohanty, "Machinery Condition Monitoring- Principles and Practices" CRC Press, 2014.
- www.iitnoise.com
- Contact Prof. A. R. Mohanty at 94340-16966 or email: amohanty@mech.iitkgp.ernet.in

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So, some of these examples which we discussed in this are given when my in an appendix so, all of you could perhaps try it out on your own using MATLAB. So, with this examples you know you got a feeling of how MATLAB could be used for signal processing. And then of course, in a later on I will showing you how such signals can be physically generated, and what kind of signals machines give out, and what kind of analysis, we can do either to a dedicated frequency analyzer or the software like MATLAB ok.

Thank you.