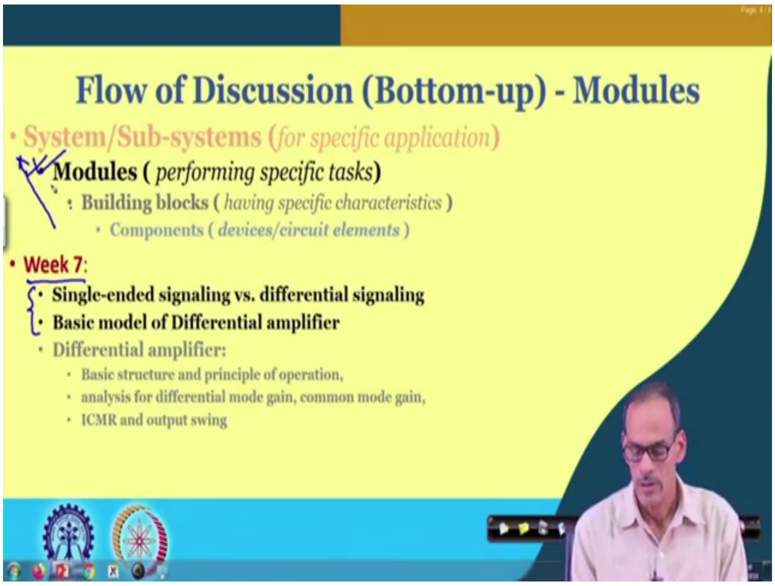
Analog Electronic Circuits
Prof. Pradip Mandal
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 72
Single- Ended vs. Differential Signaling and Basic Model of a Differential Amplifier (Contd.)

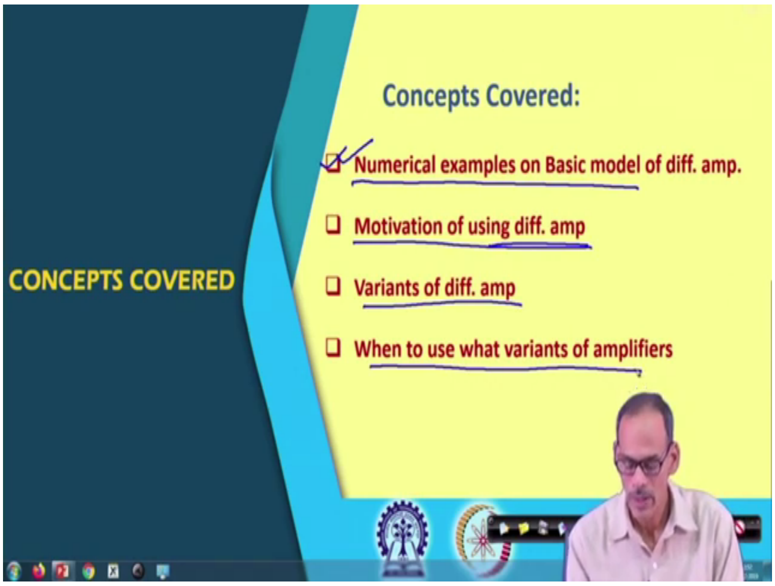
Dear students, welcome back to our NPTEL online certification course on Analog Electronic Circuit; myself Pradip Mandal from E and ECE department of IIT Kharagpur. Today's topic of discussion, it is Single Ended to Differential Signaling and Basic Models of Differential Amplifier. In fact, this is continuation of our previous lecture. So, we are going to continue on the basic model of differential amplifier.

(Refer Slide Time: 01:02)



If you see the overall plan; we are in module 7 and we are continuing the first 2 items of a module 7. And in the overall structure wise we are at the module levels of the circuits. In fact as I said that it can be considered differential amplifier it can be considered either block level or module level depending on the perspective and in this course we are focusing this topic differential amplifier as module level discussion ok.

(Refer Slide Time: 01:55)

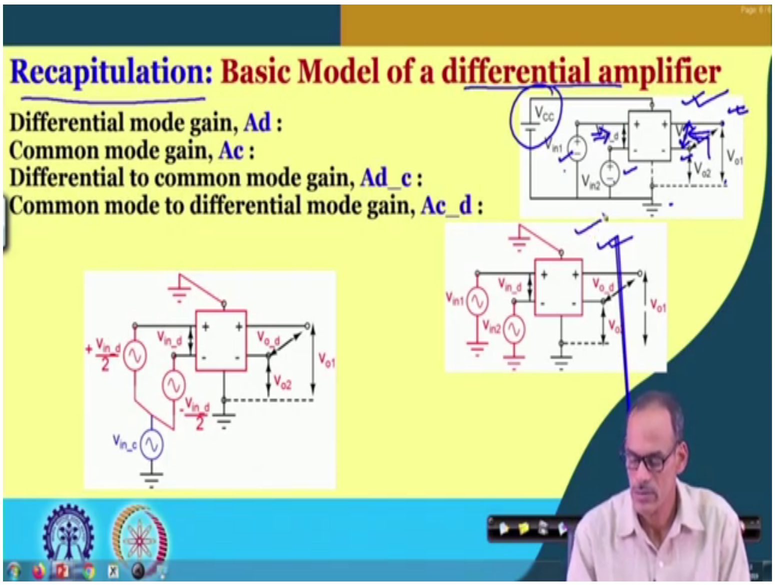


Now the concepts we are planning to cover here, it is the following. So, yesterday or in the previous course, in fact, previous lecture we have discussed about numerical examples. So, we will continue some more numerical examples and based on the basic model of differential amplifier to highlights what are the importances of different performance parameters of the differential amplifier. After that we will be talking about the motivation of using differential amplifier.

So, we are expecting after the first topic, we are expecting that we will be having fair understanding of the behaviour of differential amplifier and then we will be talking about where and when we need to use differential amplifier. Particularly, we already have discussed about single ended amplifier. So, we have to discuss about the situation where single ended amplifier may not be the preferred one rather we want differential amplifier.

And then we will be talking about different variants of differential amplifier starting from the basic one which we have we already have started. And then, we will be talking about which variants of the amplifier should be used in what condition right. So, coming to the topic, we have discussed in the previous class namely, the basic model of differential amplifier.

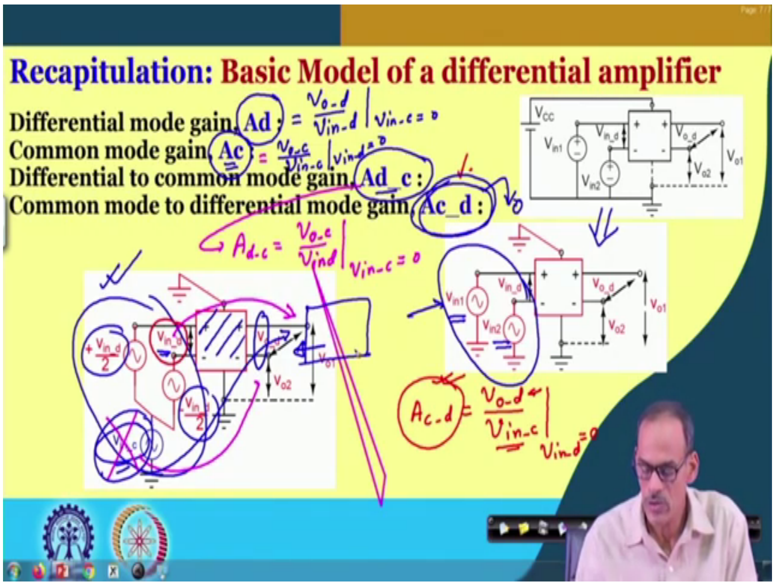
(Refer Slide Time: 03:31)



We can consider this is the recapitulation of whatever we have discussed in the previous lecture. Here we do have the differential amplifier as I said that the input port it is differential in nature, output port is also differential.

We do have the main supply voltage and then we are feeding the signal at the input port by say to single ended signal. And then at the output, we are observing the output either at individual terminal output terminal with respect to ground or more appropriate way to say that we can observe the signal in the differential form.

(Refer Slide Time: 04:47)



And then as we have discussed in linear single ended amplifiers linearization so, this differential amplifier can be linearized. And so, we do have the linear model here of the differential amplifier and then at the input either we can think of that we do have one pair of single ended signal or we may consider that it is carrying differential signal and maybe it is having also common mode signal. So, we can represent this pair of signal in this form, namely in terms of common mode component and the differential component.

And we have discussed that why we prefer this representation of the signal input signal. Namely, because the behaviour of this amplifier differential amplifier it is it can be well characterized. If we convert the signal in the form of differential signal and common mode signal and then we can say what may be the corresponding output we get out of this circuit.

And also we have discussed about four important performance matrices namely, differential mode gain common mode gain and then differential to common mode gain and then common mode to differential mode gain. As you may recall the differential mode gain, it is defined as output differential by input differential. Assuming that the common mode signal it is 0 v in c equals to 0. So, likewise we can define the a common mode gain which is v o c divided by v in c when differential component of the input namely v in d equals to 0.

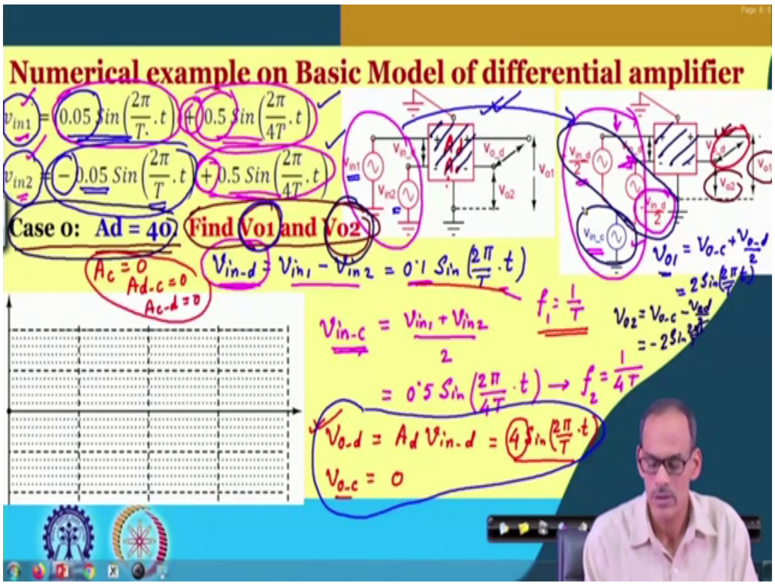
So, likewise if we consider the other two parameters namely, differential to common mode gain which is defined as the differential signal is getting convert into common mode; that means, v o c divided by v in d when we do have the v in c equals to 0. So, likewise we can define this this parameter namely, A c d equals to and so, this is converting the common mode signal in the form of differential. So, this is v o d by v in c when we do have a situation where input differential signal equals to 0.

And as I said that this parameter it is very dangerous thing, particularly we should pay lot of attention. So, that this parameter should be as small as possible ideally should be 0 that is because it converts common mode signal in the form of differential signal. And whenever we are talking about differential amplifier its basic purpose here it is to appreciate the differential signal and also to suppress this common mode part. Now if the differential signal it is coming as is in the form of differential, then there is no problem. If the common mode signal it is coming here, then also it is ok. But then toward this output we may not be able to really separate this unwanted signal.

So, in summary this parameter which we one this should be as small as possible ideally should be 0. On the other hand if say A c or A dc if they are nonzero, but then we may say that we can put one more differential amplifier to further suppress the unwanted part and we compare to the wanted part, namely differential part or we can say that we can appreciate the differential part and then we can suppress the common mode part.

So, this is what we have discussed in the in the previous class and let we go for some numerical example.

(Refer Slide Time: 10:06)



So, yeah so, here in this numerical example, we are going to start with the linearized model. So, we do have the main circuit here and the input we are applying here, which are given here in terms of see differential part and common mode part. So, if you see here, both the signals both the signals are having two frequency component.

So, depending on this T so, this part first part it is having a frequency of 1 by T and its amplitude it is 50 millivolt. So, this is of course, unit it is volt. On the other hand if you see the second part, if you consider the second part it is having a frequency which is 1 by 4 T and its amplitude it is 5 oh sorry 0.5, 0.5 volt; that means, 500 millivolt. So, on the other hand if you see the second signal its differential part or the first component if you see, it is also having the same frequency of 1 by capital T and its amplitude it is 50 millivolt, but it is having a minus sign. And so, if I take the difference of say v 1 minus v 2 v in 1 minus v in 2 to get the differential output v in d.

So, what we are getting it is 0.1 sin 2 pi by capital T into t. So, these two part the other higher frequency part this part and this part. Since they do have the same sign once we subtract this two input they are getting cancelled out. So, we can say that differential input it is having 100 millivolt amplitude and the frequency of 1 by capital T. On the other hand if I take the average of these two signals; if I take average of these two signals to get the common mode component namely v in c. So, that is equal to v in 1 plus v in 2 by 2 and this is equal 0.5 sin 2 pi by 4 capital T into t. And its frequency it is of course, if I call f 2 is equal to 1 by 4 T.

So, this unwanted signal or common mode signal it is having a frequency one-fourth of whatever the wanted signal or differential signal. Now once we have this signal paired v in 1 and v in 2 represented in terms of v in d and v in c, then probably we can represent the stimulus in this form. Where this signal it is submission of v in c plus v in d by 2.

So, this is the v in c part and then this is the v in d by 2 part. And the signal coming at this point on the other hand, we do have v in c and then minus v in d by 2. So, this is the common mode part and then we do have minus v in d by 2, it is given here right. So, once we get this information the particularly the signals are getting represented in the form of differential part and common mode part, then probably we can look for the signal coming out of the differential amplifier by considering its corresponding parameters.

So, what are the parameters we do have? We are expecting it will be having a differential mode gain and then common mode gain and the other two parameters. Now suppose we will be considering different cases and to start with ideally we want this circuit should be having differential gain should be as high as possible and then the other parameters should be as small as possible. So, to start with let we consider say case 0 or ideal case where differential gain it is 40 and let we assume that the other parameters are 0.

So, if that is the case and we like to know what will be the corresponding output; either you can think of the output signal in the form of differential part and common mode part or maybe we can think of the individual signal with respect to common node. So, either it may be in this single ended form or maybe in this differential form ok.

Now we will be talking about that namely once we have this information of say differential gain 40 so, from that we can see that v od equals to Ad into v in d right. And that is coming so, we can multiply this this signal with 40. So, that gives us 4 sin 2 pi by capital T into small t. So, which means that at this differential port we obtain a signal having a frequency f 1 which is equal to 1 by capital T and its amplitude it is it got increased from 100 millivolt to four volt right.

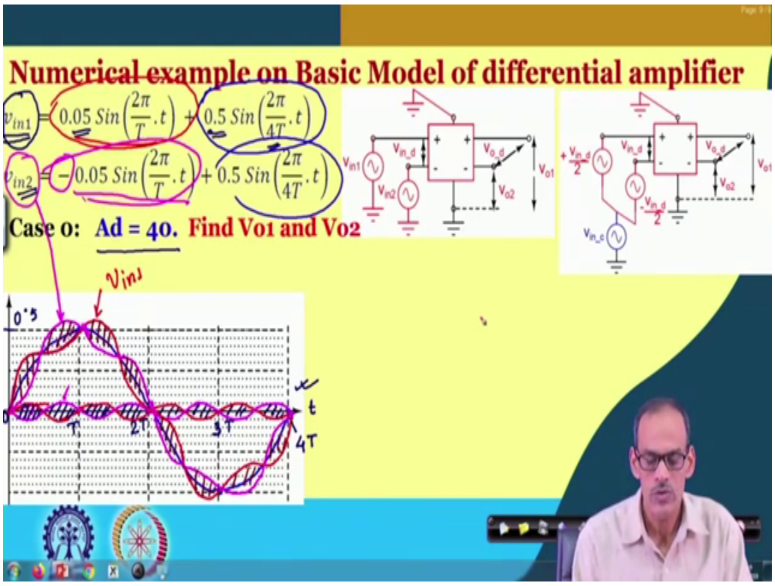
And if you see the common mode part on the other hand v o c, since the A c a we are assuming that A c is not given to us. So, we can assume that this is 0 and in fact, we can consider A dc equals to 0 and A cd it is also 0. So, if I consider all of them are 0 then we can say that this is the shoal v out and v o c of course, it becomes 0.

So, that gives us the individual signal namely, V o 1. So, that gives us the v o 1, let me use this space. So, v o 1 equals to, now we can convert this this representation of the output information in terms of a pair of single ended signal namely, v o 1 equals to v o c plus v o d by 2 which is equal to 2 sin 2 pi by capital T into t. So, likewise if I consider the other signal namely v o 2 so, that is equal to v o c minus v o d by 2 and that is equal to minus 2 sin 2 pi t by capital T.

So, this is what the signal we are getting here. So, as I said that this is ideal case. So, we want this block should be intelligent enough. So, this block should be intelligent enough. We suppose to appreciate the differential part namely it should amplify the differential signal and it should completely ignore this common mode signal.

So, pictorially let we see what is its you know the corresponding input and output and how we can further explain that what is the basic motivation of using this differential amplifier.

(Refer Slide Time: 20:13)



So, here we probably we can. So, we can use this graph. So, I have prepared this graph. So, that we can probably sketch the waveform say for example, if you want to sketch say v in 1 and v in 2. And since we do have this signal which is 10 times higher than this signal probably the scale we can consider here it is say this is 0 and this is maybe is a 0.5 right. And the signal here it is having a frequency of 1 by 4 T. So, we can consider this as the time period.

So, this we consider capital 4 times capital T, this is 2 T, this is T and this is 3T and so and so. Now, if we consider the common mode part; so, this part which is there for both the signals. So, it may be having a amplitude of this much. So, the signal should be going through this point, this point, this point, this point and this point. So, let me consider the common mode part and then if I consider the differential part. So, if I consider only this part and its amplitude is just to one tenth of this, which means that its amplitude should be only one of the scale. So, this part so, it is having different frequency sorry, this should be having a period of T.

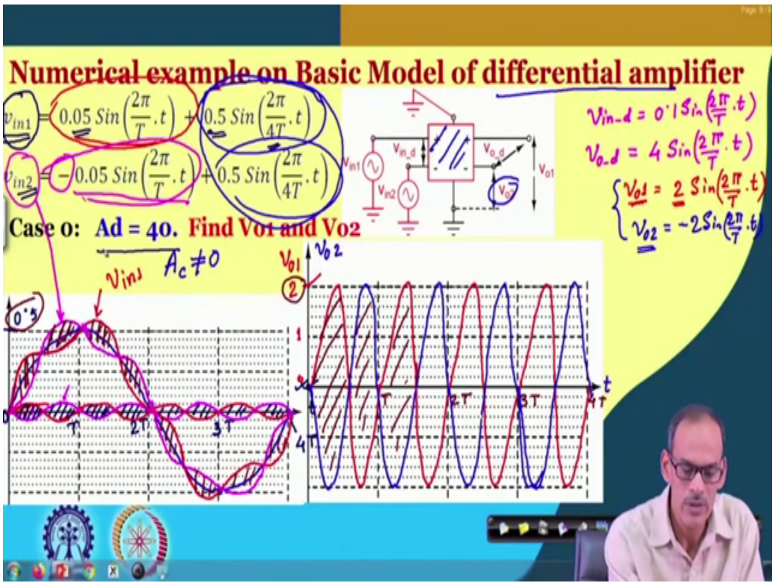
So, it should be going like this and it is having in fact, 4 cycles right. So, this is the differential part I should say rather half of the differential part. And if I consider the other half of the differential part which is having minus sign so, this is just complimentary of the red colour signal ok. So, we do have the differential part it is represented here and if I take the difference of these two signal; difference of these two signal it is essentially the wanted part which we like to process or amplify.

And on the other hand this blue colour part we like to eliminate. And this is this can be done by these differential amplifier which is having a gain is 40 and this this is actually differential gain so, which is amplifying this signal. Now in the yeah so, if I consider the total signal of course, if I consider this total signal; it is a combination of this blue and the red. So, let me try to sketch that.

So, if I combine this blue and red and if we see the signal coming like this let me use red colour just to represent it better right. And then here yeah here we go. So, this red colour is essentially v in 1. On the other hand, if I consider say v in 2 let me use pink colour so, if I consider this part. So, I need to add this pink colour signal with the blue one. So, I do have the signal going like this.

And so, if I see the individual signal we can see that compared to the blue line the differential part it is really small and it may be scary how we can really separate it out this wanted part from the unwanted part right. So, this violet colour, pink colour, this pink colour is v in 2. Now out of this we also said that we have we have considered the v out in the particularly differential part which is 4 sin 2 pi by capital T by into t. So, let us try to sketch that in the next slide yeah.

(Refer Slide Time: 26:28)



So, we do have the input signal, we are keeping as is and we are trying to sketch them yeah we are trying to sketch the output. Now when we will be sketching the output we may recall that v in d equals to 0.1 sin 2 pi by T small t and that gives us v od equals to 4 sin 2 pi by capital T into small t right. And from that we obtain v o 1, v o 1 equals to half of this v od which is 2 sin 2 pi by capital T into small t. And the v o 2 equals to minus 2 sin 2 pi T into small t. And let we say use a this graph to sketch this two output.

And so, here we do have the time axis and here we do have the output signal can be plotted along this y axis. So, if we consider say v o 1 and its amplitude it is 2 volt. So, in this graph probably, we can consider this is 2, this is 1, this is 0.And so, the v o 1 which is having a frequency 1 by capital T, let you consider the same timescale.

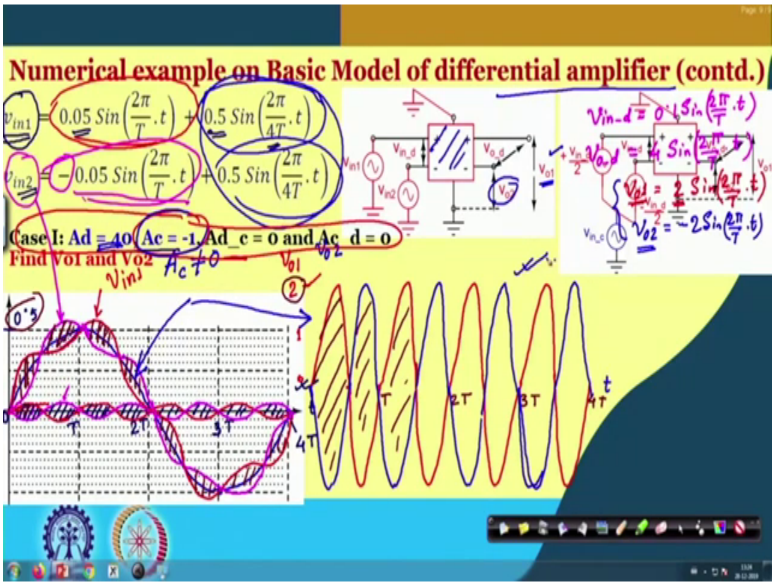
So, we do have T, 2 T, 3 T, and 4 T. And we do have the signal v o 1 which is having an amplitude of 2 and the time period of capital T. So, which means that v o 1, its sketch it is like this. So, it is having an amplitude of 2 volt and a frequency of 1 by capital T right. On the other hand if I consider the other output namely, v o 2. So, let you consider v o 2. So, that signal it is coming this complimentary of it right.

And now we can see that the signal what about we are looking for that got nicely amplified. And the unwanted signal unwanted signal it is completely getting removed. So, if as I said that we are looking for this part or whatever this part shaded part which is wanted that part it is coming here with nice amplification. Note that this scale and this scale they are different, in fact, if you are putting in the same scale; obviously, this signal could have been much bigger.

So, that is the basic purpose of this differential amplifier namely, suppressing the unwanted part. Suppressing the unwanted part which is probably it is having some reason somehow it sneaks into the signal and it is trying to corrupt the signal. But then we do have this magic block called differential amplifier which is helping us to completely suppressed that. Now practically; however, this common mode gain A c need not be 0. In fact, the other parameters may also be having some significant value.

So, let us try to see what may be the consequence only you have a situation where a common mode gain it is nonzero along with the differential gain maybe remaining as high as 40 ok.

(Refer Slide Time: 32:32)



So, now here we do have a situation, here we do have a situation sorry, the I am trying to return this waveform. So, that you can appreciate that what are the things it has happen in between or earlier what was the situation. Now if you see I have change the condition namely.

Now, we are considering a second or case 1, we say where it is not ideal situation namely this is non 0 and since it is nonzero we are expecting that there will be some difference in this output signal or to be more precise this common mode signal, the blue colour signal it may be having some influence on this part.

So, in the next exercise what we are going to do it is basically trying to see what will be the corresponding individual output and then I must say that once you have say clean nice output, probably one of them is good enough to extract the information. But in case if we have say common mode gain which is nonzero, then probably the signal coming here either v o 1 or v o

2 may not be as clean as what we are plotting here instead, it still may be having some unwanted signal.

So, let us try to see in this situation what may be the unwanted component ok. So, let me take a small break and then we will come back.