Biomedical Signal Processing
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Lecture – 50
Tutorial – II

So, now, we will start the equation 2.1.

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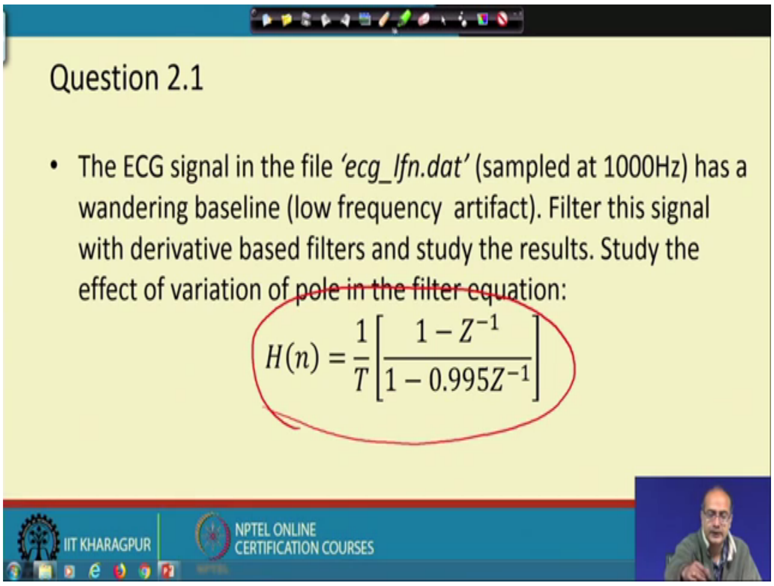

That is the question here from the tutorial 2, the first question is that ECG signal we have taken the ecg underscore lfn dot dat that this is suffering from a artifact called that low frequency artifact that it is having the wandering baseline. So, we need to use a derivative base filter to remove this artifact and we need to study that how successful the derivative felt based filter is.

Next, we would add a pole to it and here is the equation given for the pole that we would like to see that by adding the pole how actually that the situation improves or gets degraded, ok. So, that is the part we are looking at.

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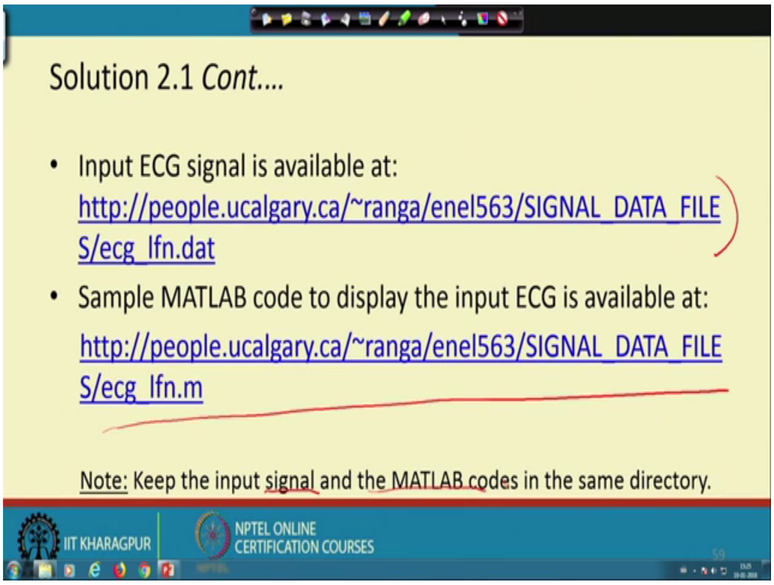

Now, to start this exercise first we need to collect the data file here we have provided that the location of the data file that where we can get it and we have also provided that where we can get the MATLAB code to read that file, that is also is given here and again we need to keep in mind that we need to put the signal as well as the MATLAB file in the working directory of the MATLAB, ok.

So, these are the preconditions. So, after setting it up we are in a position to start the exercise.

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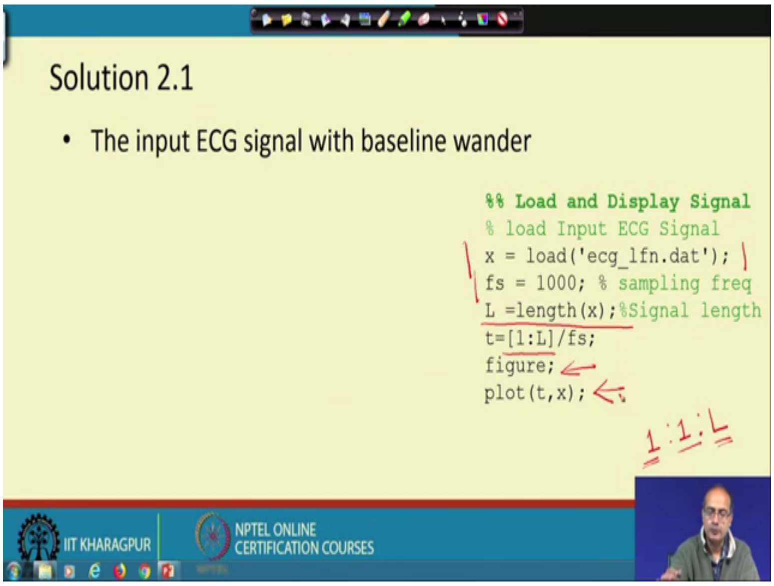

So, here the input signal is suffering from the baseline wandering. So, first what we have done we have to load that data file. So, we have loaded it and we kept it in the variable x. Next, we look at that what is the sampling frequency that is given sampling frequency is thousand we initialize the variable fs with the sampling frequency. Next, we would like to get that what is the length of the data file or the variable x; it means that what are the number of samples we have provided with that we would like to know. So, we write that actually in the variable L using the comment length of x next we would like to see the plot of the signal.

So, for that so, first we need to create the x axis or the time axis. So, we have taken a ramp from 1 to L samples. So, that we can create by using the third bracket and within that if we give colon that here we have used that 1 colon L actually we could have written it in this way the full syntax is like this that this is the starting point this is the end point and this is the increment.

So, as a default increment is one we need not have to give this, and as we are looking into we want to plot it in terms of the time rather than the sample number. So, we have multiplied it this vector with 1 by fs which provides as the that sampling intervals and then we create the pen by using this command figure and we have the plot here,.

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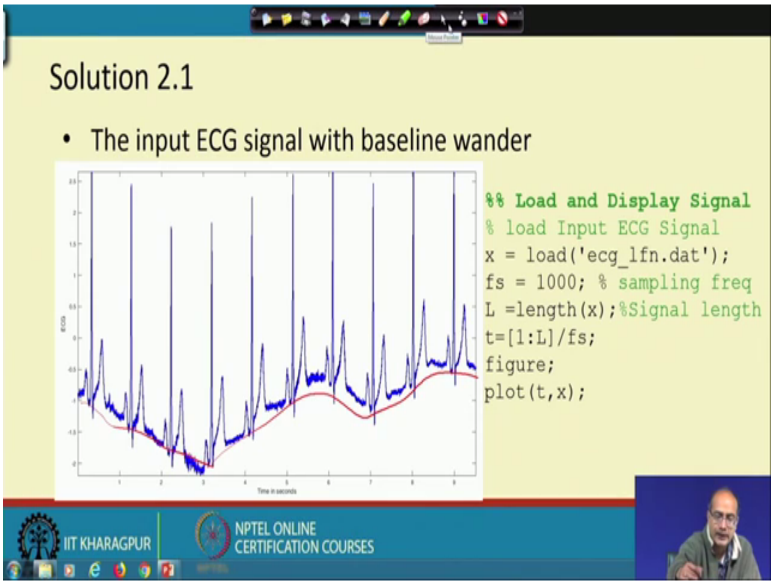

So, here we get the plot and what we notice that if we look at the baseline or the isothermal line rather than it is being horizontal it is having a variation like this, ok. It is having a variation like this. So, what we get that that this is the phenomena is called that baseline wandering and as it is moving much slower than the ECG wave it is a low frequency noise or low frequency artifact that we realize and now, we need to take care that how we can actually clear this one.

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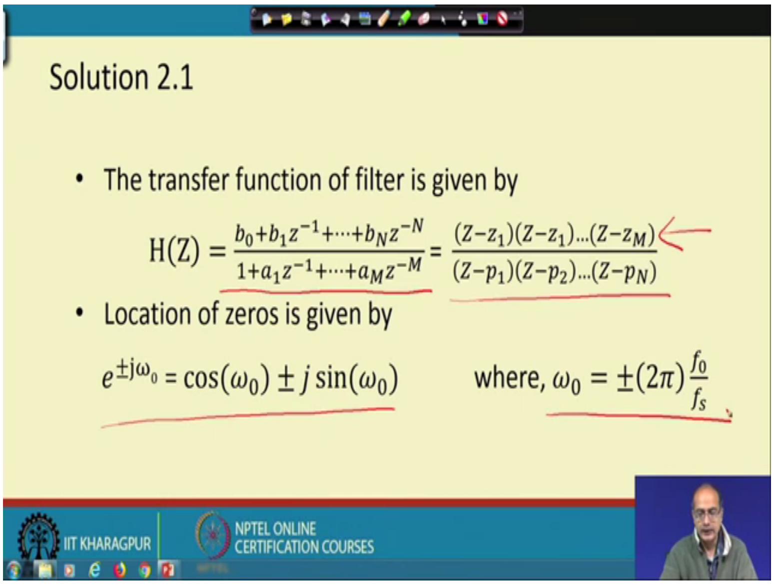

So, for that we have to use a filter and first we take the general response of the transfer function of the filter. So, we have first taken the form in the written with the help of the rational polynomial form and then we are writing it into the form of a the poles and zeros and in particular here we are looking at a derivative filter.

So, we would be looking for actually the zeros. So, we need to place the zeros at low frequency and that is what we will have to do. So, we have to create the zeros there just like a notch filter and this is this should be the pole location where the frequency is given by omega 0, ok.

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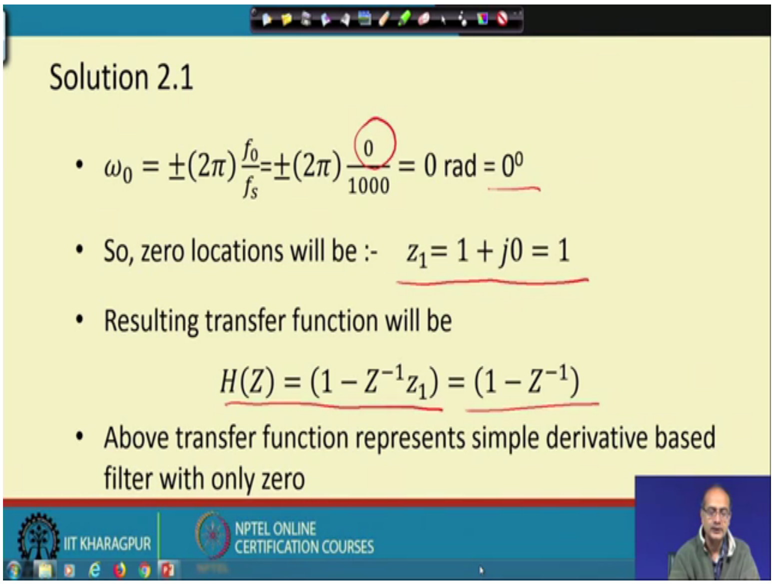

Now, as our frequency is actually low frequency. So, what we get here that that we are looking at that 0 frequency or the dc value. So, you use the same formula as the notch filter that omega 0 equal to 2 pi into f 0 by fs and f 0 is replaced by 0 and thereby we get that at 0 radian we need to get that and in this case 0 corresponding the 0 location becomes z 1 equal to 1 plus j 0 or equal to 1.

Now, in this particular case where actually that our 0 is lying on the real axis there is no that imaginary component we or the filter that is already a real filter. So, we need not have to go for the conjugate pole pair otherwise we could add actually the conjugate pole pair and get or conjugate 0 pair rather in this case and we could have the two zeros at the same location, but as it is already a real filter we do not need to use the conjugate 0. So, we are keeping here the model order as 1 and here we are getting the transfer function in this way, ok.

So, as it is a single 0 that the polynomial equation and that the pole 0 form it looks a same and that this is the transfer function which gives the simplest form of the derivative filter with only zeros. So, now, we need to go ahead look that look at that that what would be the response we get out of it, ok.

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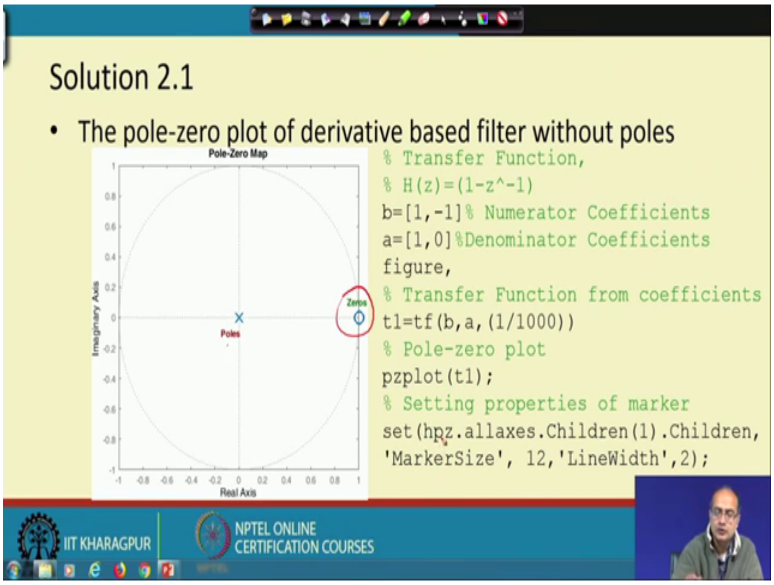

If we look at the pole 0 plot we can get some more idea about it. So, first we would like to see the pole-zero plot for that first we initialize the that polynomials or rather the polynomial coefficients b and a these two vectors. So, that numerator coefficients is represented by b and we know the that for this H z that we have that the two coefficients 1 comma minus 1 and for the denominator polynomial that we do not have any polynomial. So, we can say it 1 comma 0, ok.

So, after that to create the plot we issue a figure comment to create the pen and once the pen is created then we have to build the transfer function. So, for that that we need to call the function fn we need to make use of that function the first variable is the numerator polynomial second variable is the denominator for polynomial and the third variable is that the sampling interval, ok. As we are sampling in this case at 1000 hertz or 1 kilohertz the sampling interval is 1 by 1000.

So, and now the transfer function we get and we store it in the variable t 1. So, now, to plot that we use the command pz plot this all of them they are the inbuilt function of the MATLAB. So, you use the command that pz plot t 1 which will make that plot it will plot the unit circle as well as show the location of the poles and zeroes and the last line it is to actually set the properties of the marker to make them more visible, ok.

So, the last line actually that it is for the actually cosmetic changes which may be avoided if it is just we are want to see it for ourselves, ok. So, here we get the pole 0 plot that we get the 0 here and corresponding pole we get at the that the center. So, pole at the center does not have any effect. So, here we get the 0. So, this is the first thing we note and next we go for one to see the response of this filter.

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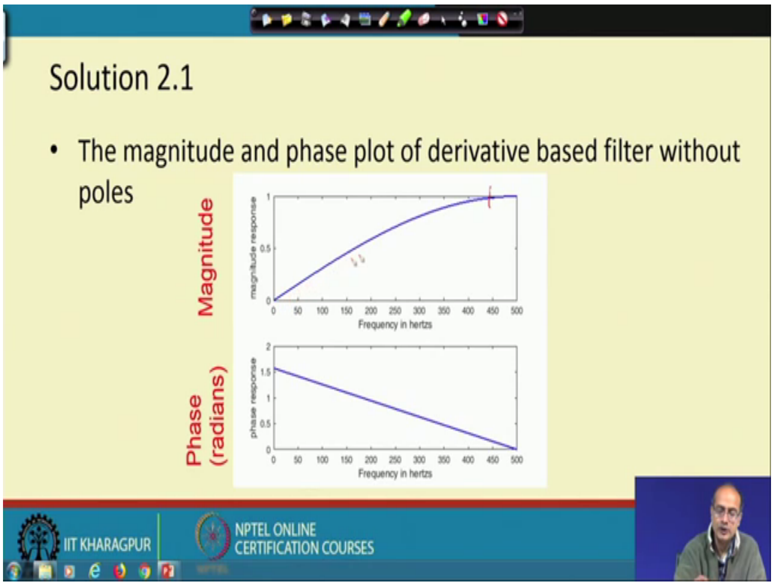

So, here we see the response of the filter that that it is response is 0 for the DC frequency and it is slowly moving up and after we can say that 450 hertz or so it is getting saturated and if we look at the that the phase plot we get it has a linear phase, ok. The phase is linear and it has a grouping characteristics. So, with the frequency we see the magnitude is increasing.

So, it is a high pass filter and with the linear phase, however, that high pass filter that transition is actually taking a lot of actually space. The transition is not sharp and what we get that the low frequency is also actually it is slowly moving towards the high frequency. So, it is not actually ideal filter rather it is pretty far from the ideal characteristics of a that high pass filter.

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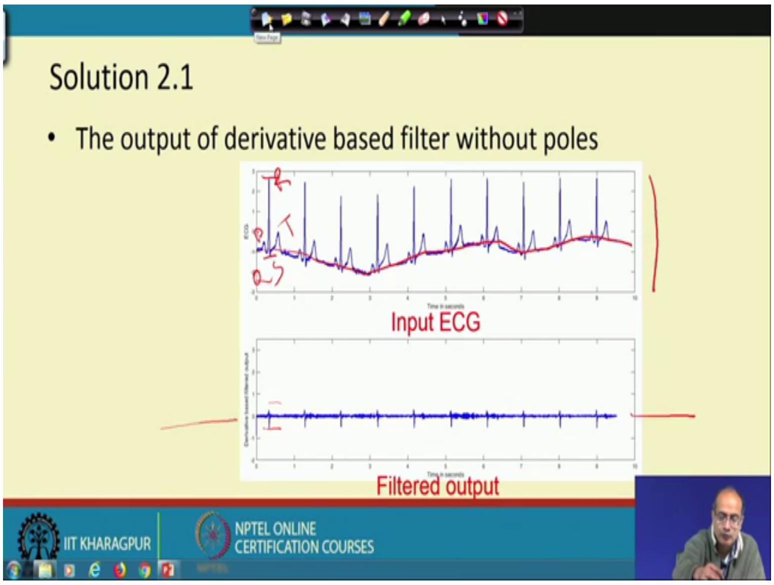

Now, let us see that what is the impact of it on the signal. Here, we show that the input signal with the baseline wandering here is the baseline wandering that we see that it is moving up and down kind of thing it is not a horizontal line and when we pass it through this transfer function; however, what we get that the noise the low frequency noise is eliminated to a great extent, and now, we are getting something horizontal. So, it has done a very good job in removing the low frequency artifact, but at the same time what we get that signal shape has become actually completely different.

And, if we look at the magnitude the earlier magnitude was about minus 1 to say 2.5. In this case it has reduced to a huge extent. In fact, what we can tell that after taking the derivative the p wave here is the P wave then QRS complex and T wave all of them they are affected. In fact, P and the T wave they are being the low frequency signals they are completely eliminated and QRS complex are having much more high frequency terms we get only a very small part of it in the output that is pretty evident from the reduction of the height of the QRS complex, ok.

So, we get that baseline wandering we got, but we will have a lot of distortion in the signal.

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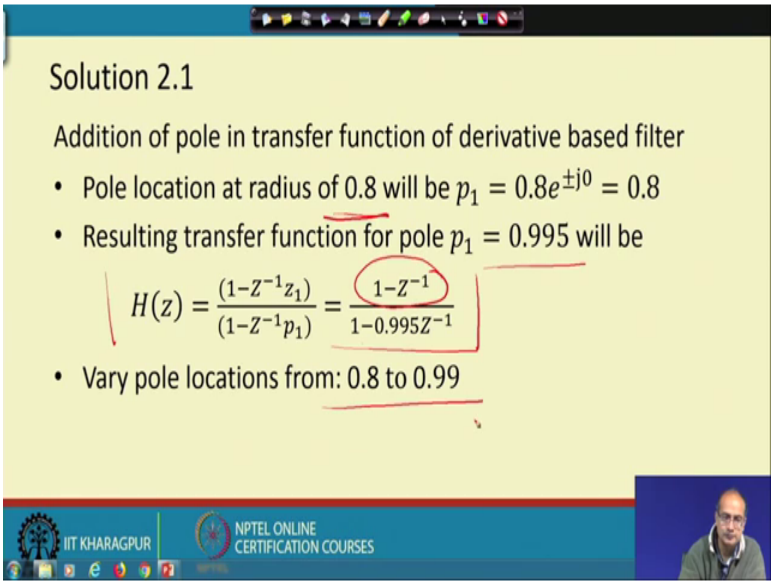

Now, let us look at that improved version of this filter and what we are call that we should use a pole and we would like to change the location of this pole from starting from 0.9 and that we can go up to 0.995, ok. So, that if we vary that the location of the pole what would be the impact of the that impact of the movement of the pole in the transfer function we would like to get that and the new equation of the transfer function would be of this form, ok.

We earlier have just the numerator part of it now we have a pole at a certain location p 1, ok. So, for the value of p 1 equal to 0.995 this is the equation we get.

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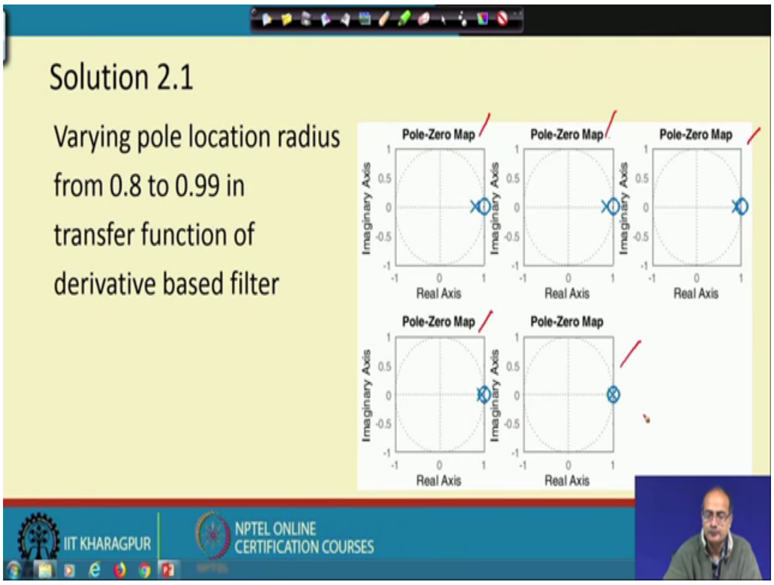

So, now, let us look at that if we keep on changing the pole location how actually it changes the pole 0 plot, ok. So, first we start with the pole 0 map at one location starting from 0.8. So, we get it here the first one then we move it further say 0.85, 0.9, then 0.95, then 0.99, ok. So, at the last it seems that the poles and 0s they are almost cancelling each other, they are becoming more and more closer to the location of the 0 and in this case one more thing we know that pole is all the time within the unit circle though it may be pretty close to the unit circle.

So, the resultant the filter what we get it would be a stable filter. So, that is the takeaway from this page and let us proceed to see that what is the impact we get on the design.

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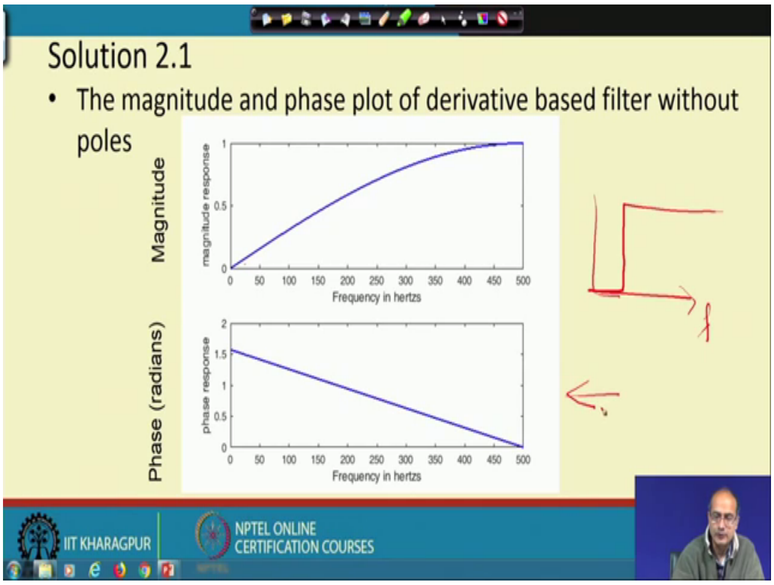

So, first we start with the that the case that where we do not have any poles. So, in this case, when there is no pole that we see that the increment of the magnitude with the frequency it is pretty slow, ok. That is the concern, that for a good filter ideal filter actually the response should be that we have a pass band that here high frequency. So, that there it should be constant and this is a stop band.

So, it should look like this. So, it is very far far from this ideal characteristics of the filter, ok. But, the good part of it is that when you look at the phase plot here the phase is completely linear ok. So, that is a beauty of this filter.

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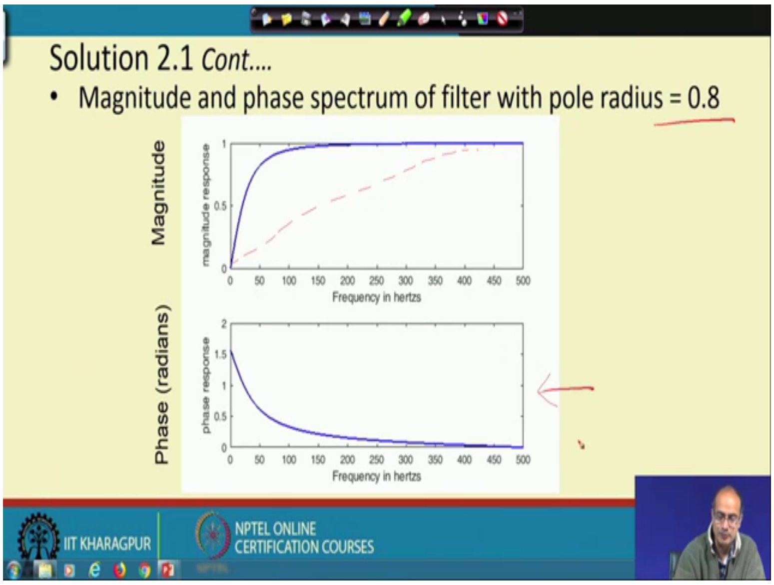

Now, let us look for the case that when we have that a pole is added and pole is added fast pretty inside at pole location is at radius 0.8, ok. So, for that when we look at the response we see some improvement earlier it was going like this now the changes are much more sharp there is an improvement in the amplitude response, but the phase respond got actually skewed we get a non-linear phase response here, ok.

So, we have a much better that frequency response or rather magnet magnitude response with respect to the frequency, but the phase response is no longer linear.

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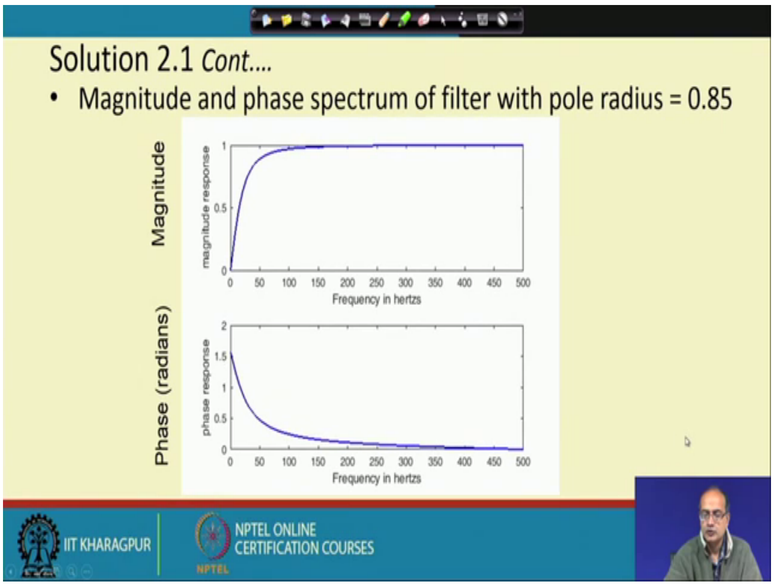

Now, let us look at that if we move the pole further away from the centre and taking it closer to the 0. So, the next step is that if we go to the 0.8. So, in this case that if we compare with the previous one, we get that the rise have become the steep that here the rise in the that frequency magnitude that with magnitude with respect to the frequency it has become sharp, but again similar sharp changes is occurring in the phase, ok.

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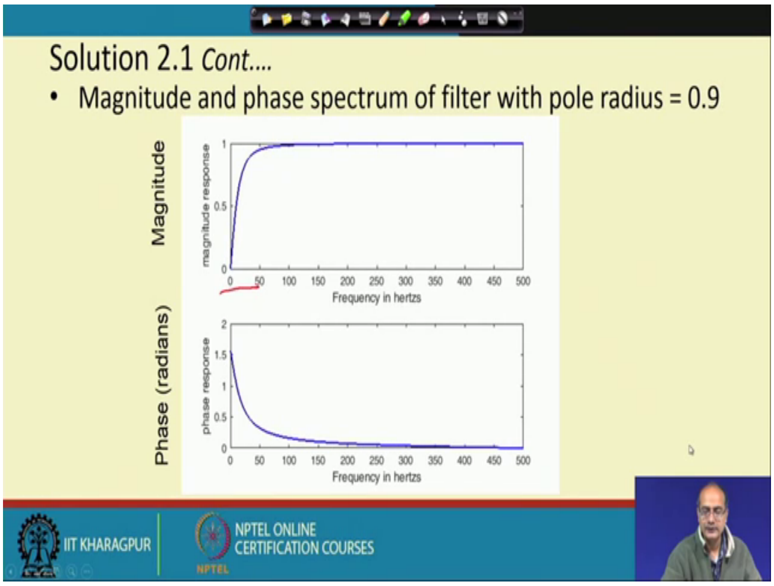

Now, we go further we look at that when if we take it the pole at the radius 0.9, then we get again further increase in the sharpness of the filter here in the magnitude plot and same way that we get more non-linearity in the phase plot.

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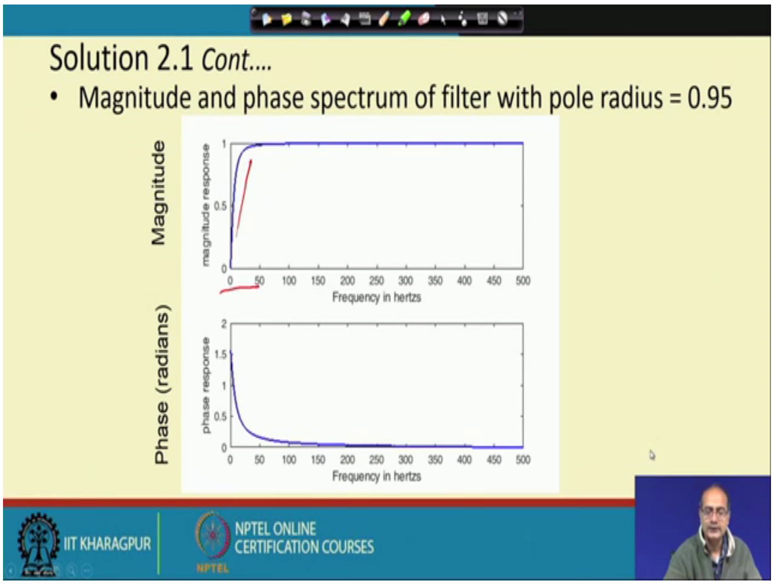

So, the next one if we look at that we get for 0.95 it has become actually much more sharp, and to appreciate that what we can do we can try to draw the line along with these and we can actually move back. We see that 0.95 what we could get we are actually when we are going to taking the pole more inside that is towards 0, we are actually moving away from that thing and the sharpness is lost.

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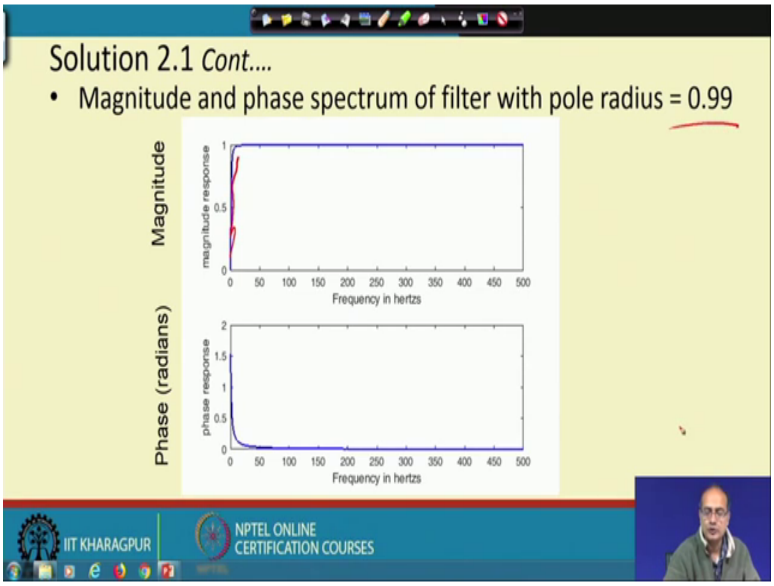

Next, we go for that the location 0.99. So, 0.99 means it is almost at the same location as the 0. So, we are getting and almost ideal characteristics they are and for the frequency that with respect to that the phase also changes in a very sharp way and for most of the actually region the phase distortion is zero. However, at the beginning there is some change and the change is very sharp, ok.

So, the best filter we can say among them for the removal of the artefact. This low frequency artifact seems to be the last one where the 0 location is that at radius one and the pole location along with it is at the radius 0.99. So, now, we should look at that how the signals look like in this case.

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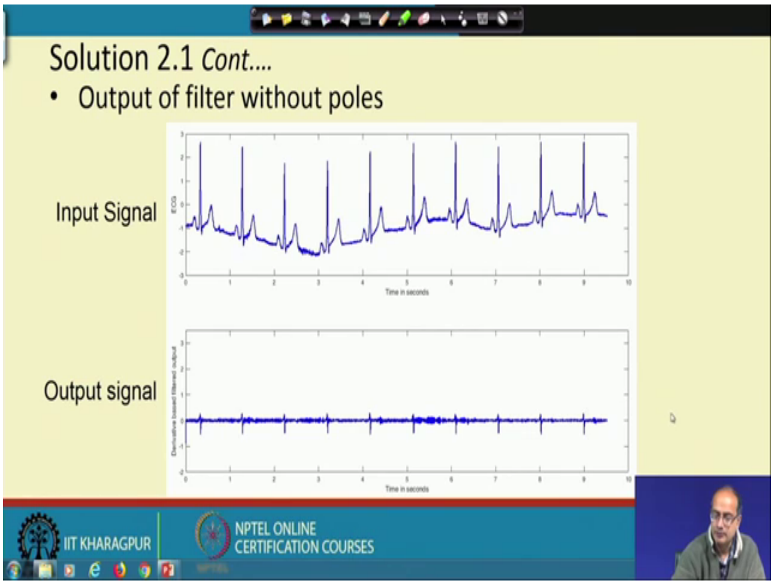

So, first we get the signal that when there is no pole in the derivative filter or the simplest case. So, what we know notice the baseline wandering has moved, but the signal amplitude is reduced to a great extent we have lost the P wave we have lost the Q wave and the QRS complex is also almost lost, ok.

We have hardly any signal left in the original from this for original signal in the output though that we are very successful in removing the baseline wandering we lost a good part of the signal energy, ok. That is very evident from the shape.

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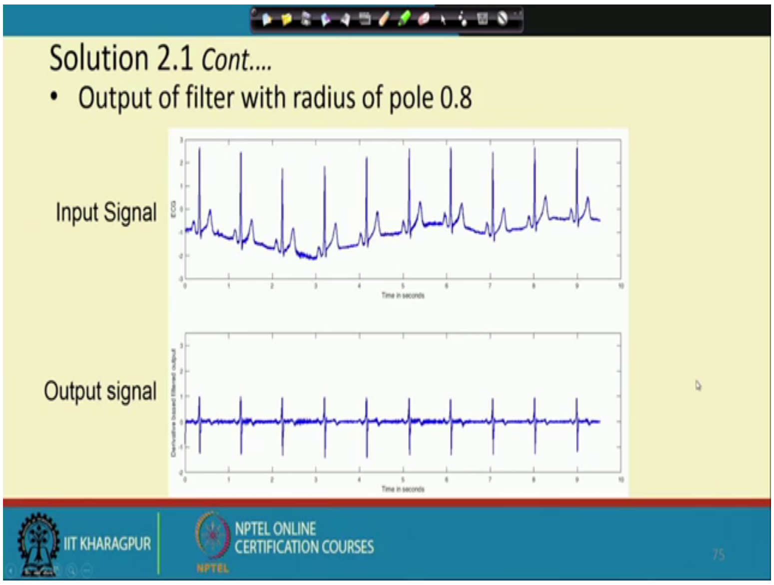

Now, let us go for the next case when the pole is added and it is located at radius 0.8, we see an immediate improvement here also the baseline wandering is removed and we get that the amplitude of the QRS complex though it is not same as the that original signal, but there is a movement and it has increased compared to the previous case though there is no sign of actually P and the T wave in the output, ok. They are still completely lost.

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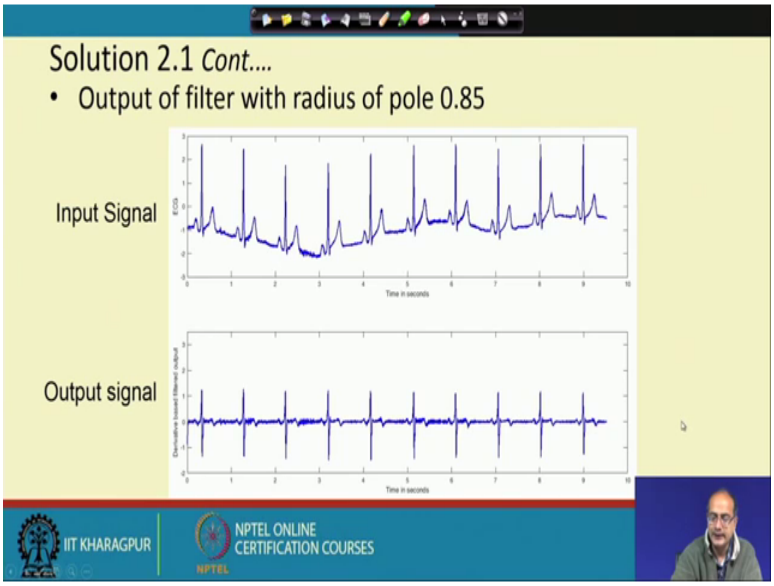

Now, let us look at the next case. Now, if we go that to the pole location for 0.85 radius if we set it then we get that again there is an increase in the that amplitude of the QRS complex, but P and T wave they are not visible. In fact, now as the amplitude of the QRS complex has increased what we see that the QRS complex loose loops actually much different compared to the original signal, ok.

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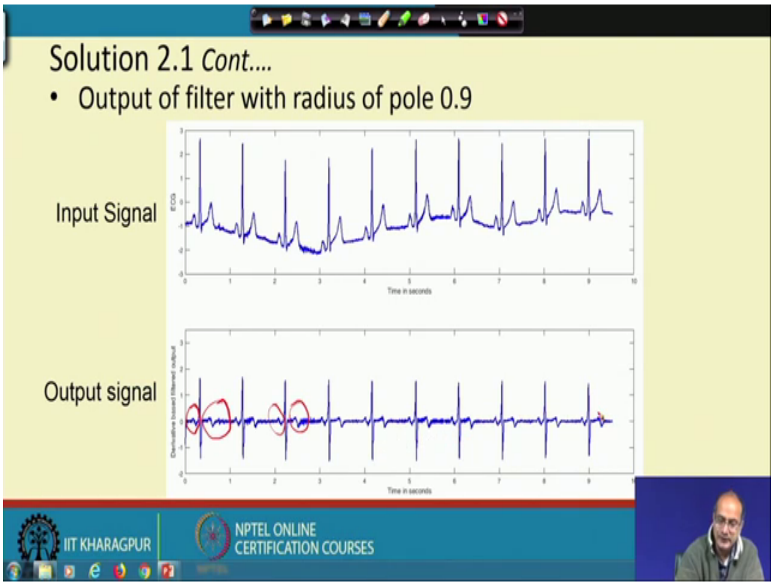

So, we move forward we move the pole location to 0.9 and for that we again witness that there is an increase in the that QRS complex output though the shape is not improved in this case and now, we get there is some output in the place of P and T wave though they do not look like the P and T wave I would like to draw your attention here, something is visible.

It looks like inverted T wave we get a oscillation like thing in place of the P wave and it is not just the first one. If you look at any cycle we get these components, and baseline wandering is actually completely removed. So, that is the common characteristics for all these cases.

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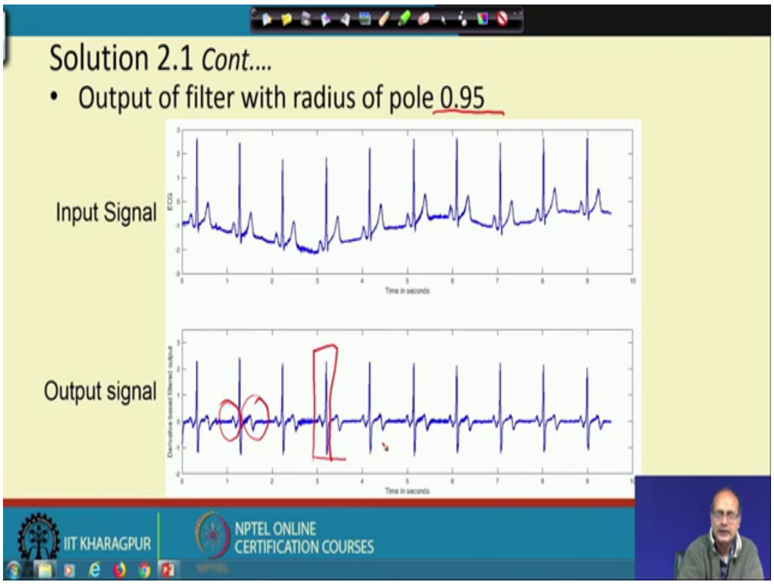

Now, we move the pole location further towards the unit circle and now, it comes to 0.95 that is pretty close to the 0. Now, what we get we get that the T wave though it has lost it is shape, but we get something and the magnitude of the T wave output it has increased the P wave also still looks like an oscillation rather than a smooth hump that both this P and T wave their shape has been impaired, but their amplitude has increased compared to the previous case and same is true for the QRS complex.

And, now the QRS complex also you would see another thing that if we look at the QRS complex that we see that there is an improvement in the shape also, compared to the previous case now it is moving closer to the that the QRS wave shape in the input signal.

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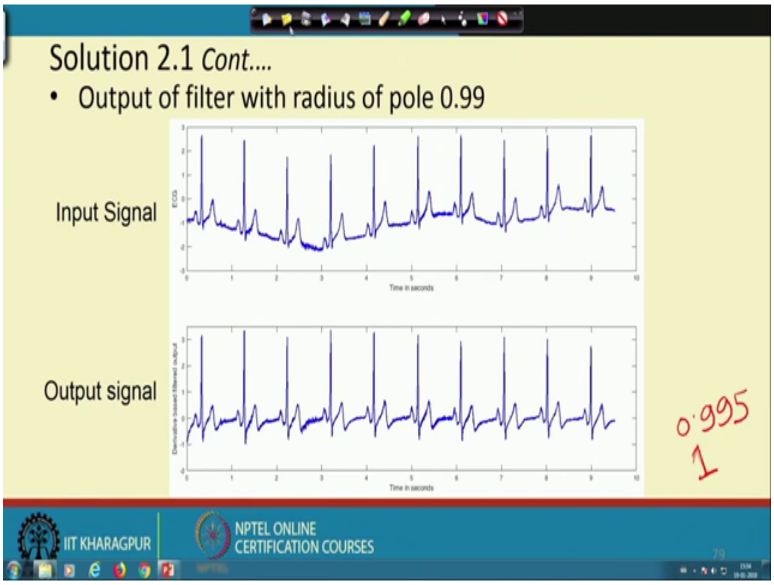

So, now you we move further to go for the pole location at 0.99. So, in that case what we find that base line is removed and the any cycle if you look at say if we take this cycle here the corresponding output it looks pretty much same as that we have the P wave which is similar to the P wave in the input signal that t wave also has come back in the output in the same way. If we look at the QRS complex say the next cycle the QRS complex it is coming almost in the same way the change in the shape is minimal and the baseline artifact is removed.

So, from that what we can get that, the last design that taking the pole at 0.99 among these examples would give us the best result among these cases. In fact, if we could put it at 995 it could be even better ok, but we need to keep in mind we should not put it at 1 because if we put it at 1 then the poles and 0 will cancel each other. So, we would not get actually it will become an all pass filter we would not get the that the removal of the low frequency artifact that is present in the signal, ok. So, that is the thing we need to keep in mind.

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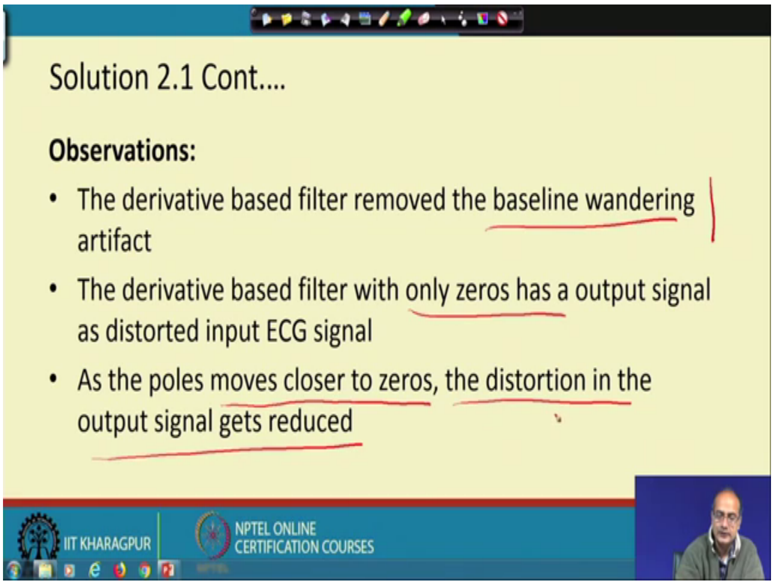

Now, we look at the observation that what are the takeaways from these experiment. First we notice that the derivative based filter is successful in removing the baseline artefact, or baseline wandering. So, all these filters whatever may be the form or the location of the pole or without pole that it is successful in removing the baseline wondering, ok; that is the first thing what we note.

Next, what we note that when we have only zeros the output signal is very much distorted, ok, that output signal the output ECG what we get it is pretty much distorted and we need to be careful about that that because our goal is not just the removal of the baseline wandering we would like to get the signal undistorted.

So, the poles are added and as the pole actually moves close to the 0 that is close to the unit circle the distortion in the signal reduces and the closer we bring we get actually less distortion in the output signal or better output signal and that is free from the baseline wandering artifact.

So, with that we complete this exercise.

Thank you.