Electronics for Analog Signal Processing - I
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Lecture - 17
Amplifier Applications

Today, we will discuss definition of amplifiers based on their applications. So far, we have discussed various types of amplifiers, basic amplifiers. Today, let us classify the amplifiers based on applications. Now, we have to bring in another term called frequency, the signal frequency. So, amplification we were now referring to was corresponding to signal, which was a voltage or a current; and it was in turn acting as a voltage controlled or current controlled input block, and correspondingly, was available as voltage source or current source. So, we had four types of amplifiers.

Now, based on signal frequency, we can classify amplifiers. Let us see how. The lowest frequency amplification, this is called, dc amplifier, d c. Here, in our case, please remember that signal in electrical engineering, useful signal, which is to be amplified, always means time varying. So, signal means actually time varying. If it is constant with respect to time, there is no information content; because, already we know that it is constant at a certain value. There is no variation with respect to time; so, there is no information content. The moment the signal varies with respect to time, then only, we consider it worthwhile signal that has to be amplified.

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Therefore, dc here means very low frequency; like in the case of biomedical signals; may be, EEG, ECG, EMG, all these signals - these are all very low frequency signals. So, such signals, if have to be amplified, must be amplified by what is called as a dc amplifier; dc means, zero frequency. But actually, in our application, it always means low frequency. Please remember this. So low, that it is almost equal to zero, you can say.

Then we have audio amplifiers; audio range. Good audio, quality signal, may be up to about 15 to 20 Kilo hertz. So, this this range of signals, when amplified, need audio amplifiers. Like radio receiver, gramophone player, cassette player, cd player, all these things will require high quality audio amplifiers. In fact, hobbies, normally electronic hobbies, normally, concentrate primarily on building audio amplifiers. So, we have about 15 to 20 Kilo hertz frequency range. Then, video amplifiers, or also called, wide band amplifiers; which will mean dc to a few megahertz; picture signal, television.

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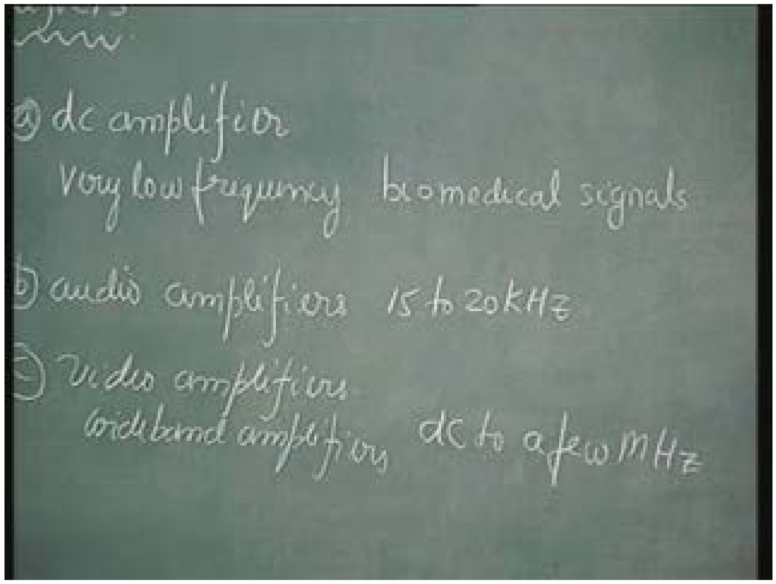

This is of primary interest to us and we want high quality wide band amplifiers for amplifying this picture signal. This is called video amplifier. In fact, therefore, our primary concern in most of the amplifier design is going to be discussion as to how to design such amplifiers; very low frequency amplifiers, audio amplifiers, video amplifiers. So, we can see the frequency range and appreciate the difficulties involved in various amplifier designs.

Apart from this, we also need to design amplifiers for already coded signals; either the signal may be FM or put in the form of FM or AM. These high frequency amplifiers which are used for FM or AM signals; these are the ones which are of interest. These are called RF or IF amplifiers. These are basically what are called as tuned amplifiers of the order of megahertz to hundreds of Kilo hertz; megahertz to hundreds of Kilo hertz. And tuned amplifiers - they may be narrow band or wide band amplifiers.

In order to make these selective, select only the carrier that you would like to amplify. These are made tuned amplifiers, narrow band or wideband, to select a band of signals and then amplify this. So, RF - radio frequency, IF - intermediate frequency amplifiers.

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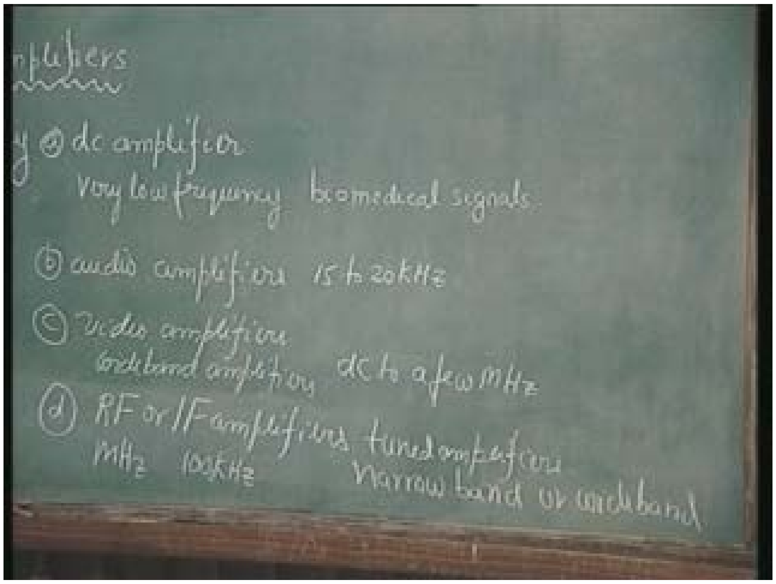

These are found as front end amplifiers in all your receivers; radio receivers or television receivers. So, these are basically front end amplifiers. These are the amplifiers which are working for the highest frequency ((... Refer Slide Time: 09:40)) and then we have... This wideband amplifier can also be used for what is called as pulse amplification. These are also the other name because these are amplifying from very low frequency; dc to very high frequency.

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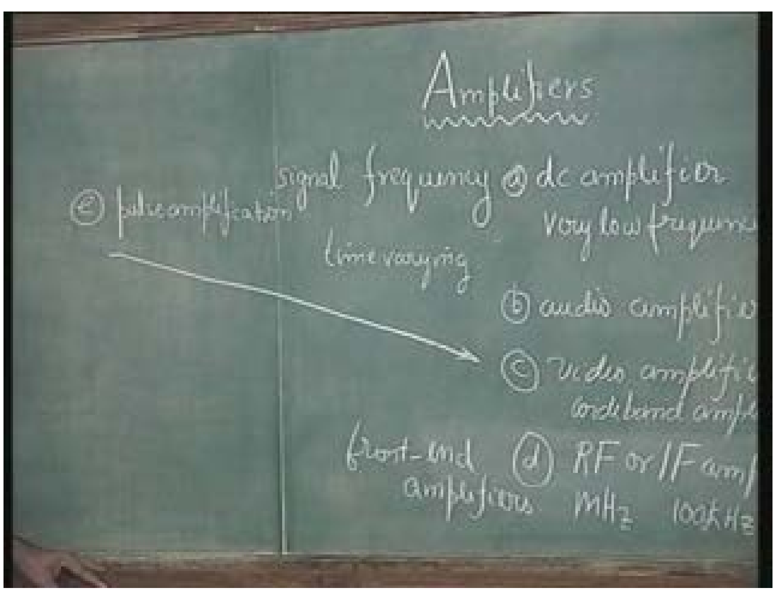

So, they are able to amplify pulses of signal. So, these are also called pulse amplifiers. So, depending upon the range of frequency, we have the various categories of these amplifications.

Now, we have to understand how frequency comes into picture ((in this... Refer Slide Time: 10:35)) .We have already understood this much; that, in an amplifier block which is close to ideal, we have this unilateral. So, we are considering that unilateral amplifier where the reverse transmission is zero. It may have a sort of input resistance R i, output resistance R naught. I am considering arbitrarily some category of amplifier, let us say, which has finite input resistance and finite output resistance; and then, let us consider open loop voltage gain, A i is K times V i; it is K times V i, open loop voltage gain, and this is what we had considered earlier. This is connected to R L. Now, it is driven by a source. This was the first amplifier we considered; non-ideal amplifier. Voltage controlled voltage source amplifier with voltage gain equal to K.

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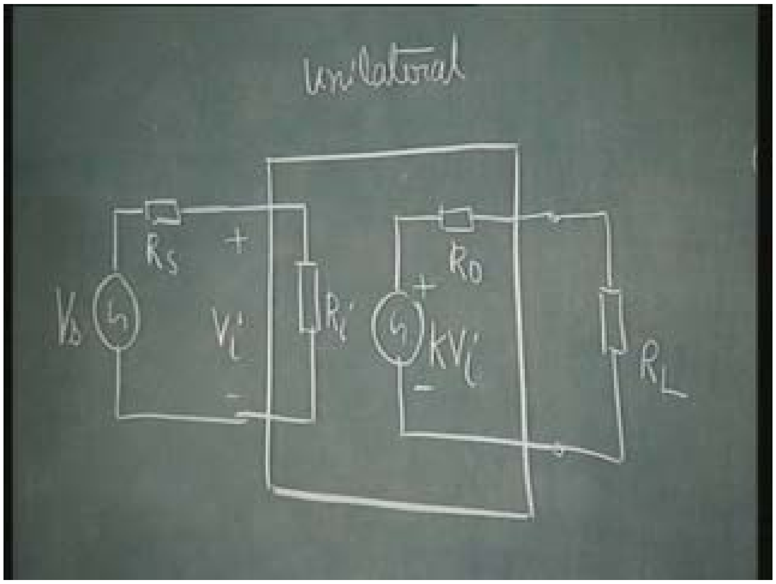

Now, let us consider: how does the frequency dependence come to this amplifier? Normally, this wiring of the amplifier and all the other connections cause what is called stray capacitors to come into picture at the input. The whole lump effect of the capacitor at the input can be put as C i. This is unwanted, but this comes. Like it, this was unwanted, if it is voltage controlled, R i should have gone to infinity; but it is there. Similarly, in general, we have the capacitor also, although unwanted, coming as stray element between the input terminals.

Similarly, at the output terminal, we have C naught as the effective output capacitance. This may take into account the capacitance due to load. Here also, it may take into account the capacitance due to source. All put together, let us say, we put it as a single capacitor C i at the input and C naught at the output.

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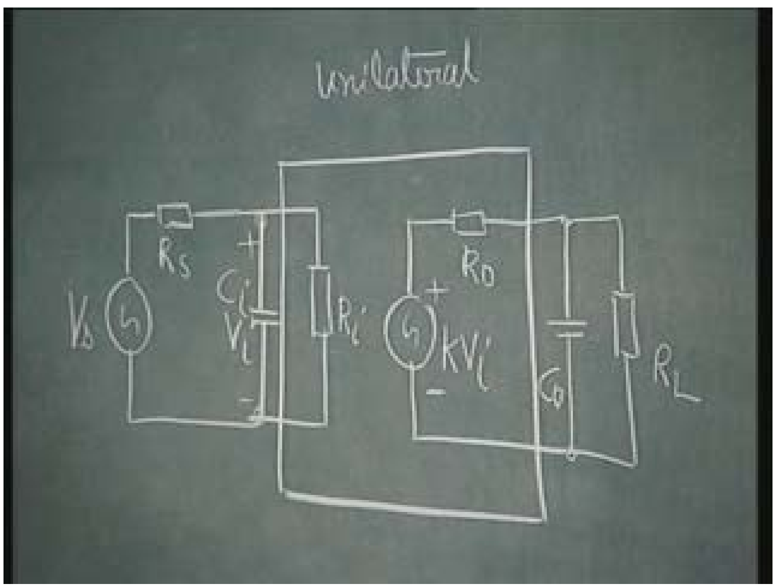

So, what does this capacitor do? So, it becomes fairly simple for us that this capacitance is going to cause V i to become much less than what it otherwise would have been because of high frequency effect. Now, at high frequencies, this capacitor will shunt this R i and therefore, most of the current which would have gone into amplifier, would have then gone into C i. So, we are going to lose some amount of signal because of C i.

Similarly, we are going to lose some amount of signal because of C naught; takes away some amount of signal current. So, what is the effect of this? This, we can easily say that, when we have a network like this, R and C; if this is V i and this is V naught for this network ,V naught over V i from network , you know, is going to be equal to 1 by 1 plus sCR, 1 by 1 plus sCR.

How did you do that? Because, for capacitance, you can consider that it is an open circuit at low frequencies. So, 1 s is equal to, put s is equal to j omega and omega equal to zero; that is dc.

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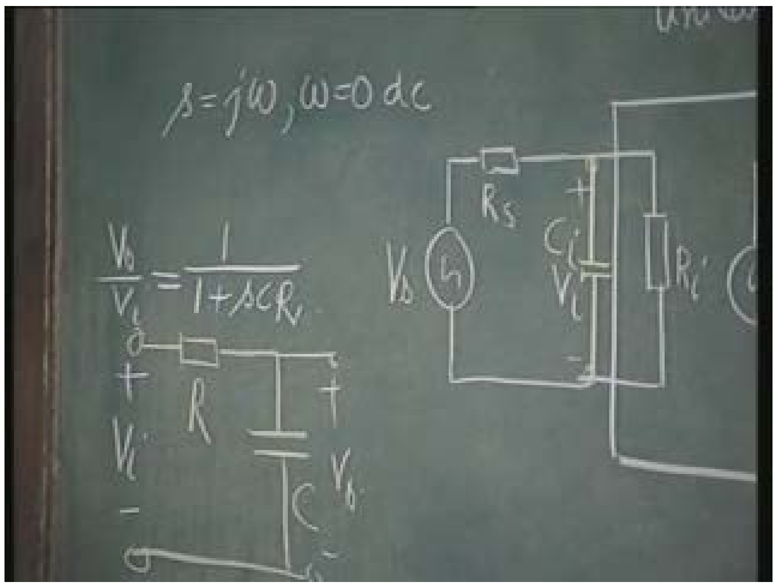

Then you get this as 1; that is true, because no attenuation occurs due to this. So V naught is equal to V i. So, this is the low frequency response of this. At high frequencies, obviously, the capacitive reactance comes into picture. 1 over j omega C or 1 over sC divided by R plus 1 over sC, is what this is; which is written as 1 by 1 plus sCR. So basically, it is 1 over sC divided by 1 over sC plus R which is written as 1 by 1 plus sC. This is the impedance of the capacitor.

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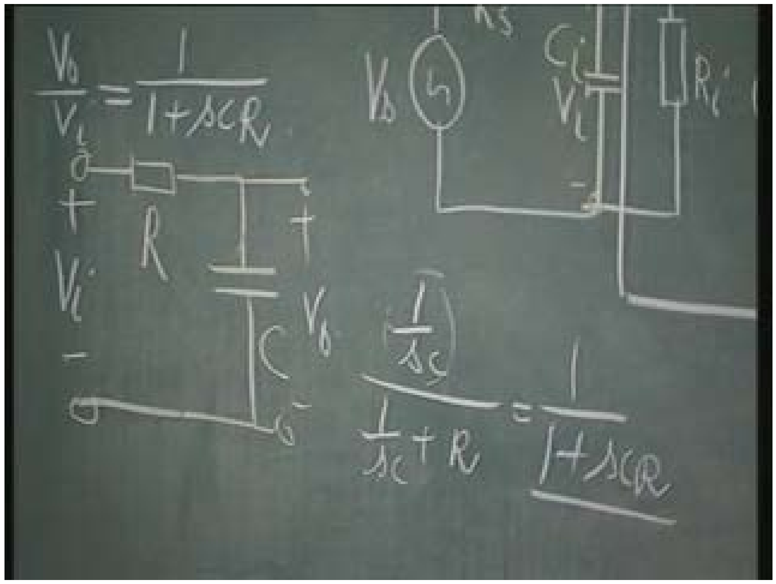

For obtaining the frequency response, you have to put s is equal to j omega. All these things you have learned in your networks course. So, this is called what? This is called a low pass filter action, low pass, low pass.

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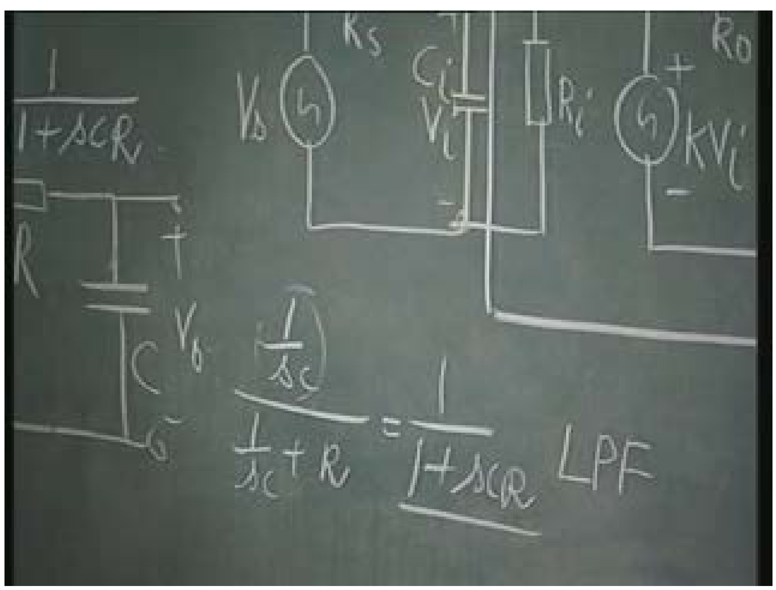

So, the stray capacitor at the input of an amplifier results in low pass filter action.

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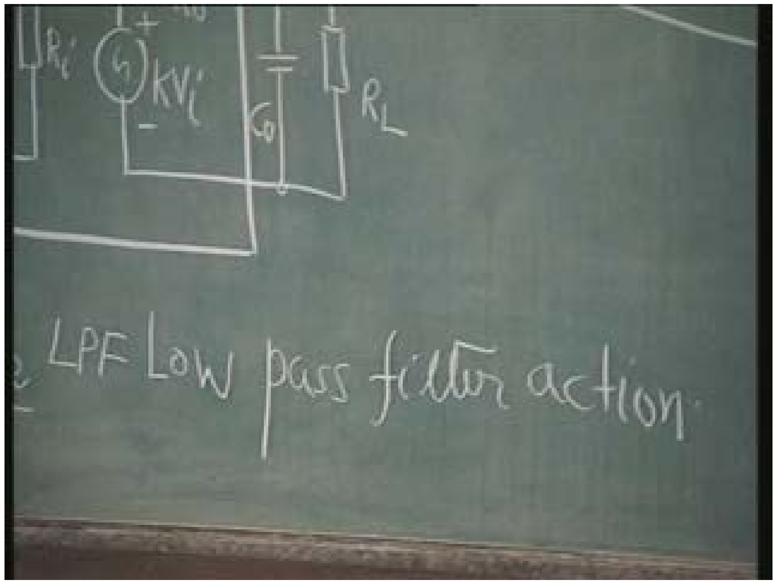

What it means is, it is going to attenuate the signal. Now, what is this R? In our case, we can replace this equivalent here by a Thevenin's equivalent. What is that Thevenin's equivalent? You can just put down this circuit at the input as R i here, C i. So, look at this from this side. This circuit remains the same. I have not changed anything. Instead of putting C i this side, I have put C i this side. This R i, I am making it become part of the input.

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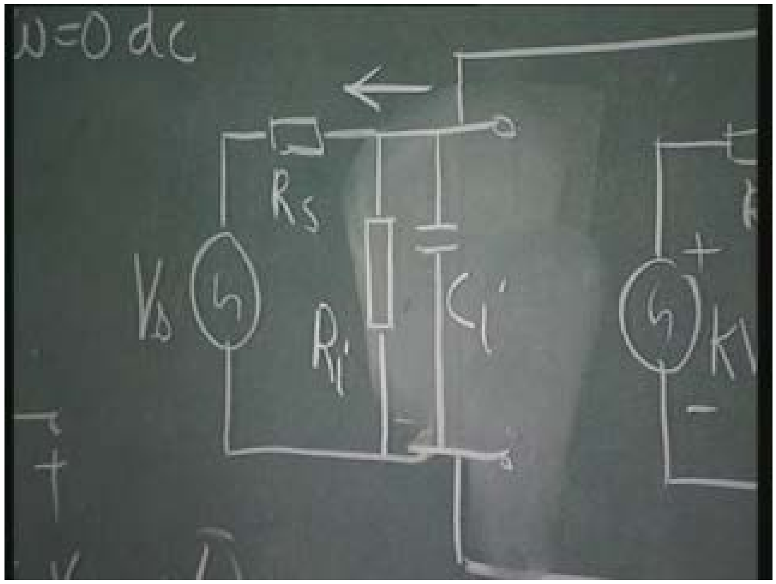

So, this is a new voltage source now, which has R i, R s and V s in this arrangement. That means, I can put down the Thevenin's equivalent for this. The Thevenin's resistance is R equal to R i R s by R i plus R s. How do I get it? Short circuit this and short circuit any voltage source and open circuit any current source and find out the effective impedance. So, effective impedance is nothing but this. So, this R is equal to R i parallel R s; and therefore, you have then the Thevenin's voltage, which is, V Thevenin is going to be nothing but R i divided by R i plus R s times V s. So, I can always convert this in this following fashion; that it is a Thevenin's voltage, V source, with a new source resistance R at the input. Is this point understood?

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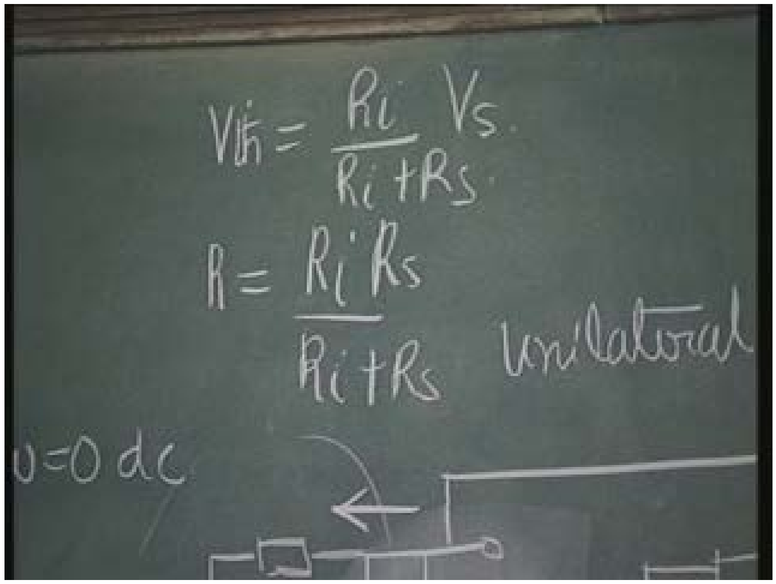

Now, if that is the case, this is nothing but this new circuit here, which we have discussed.

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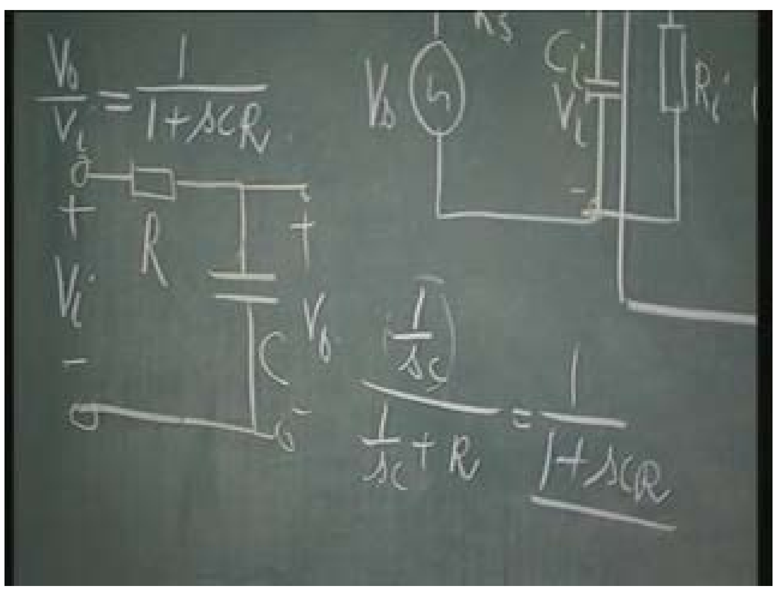

That means, its transfer function should be the same as 1 by 1 plus sCR with C being equal to C i and R being equal to the Thevenin's resistance here. So, I do not have to work out this structure for its transfer function. I can simply look at it and say that if the input capacitance is C i, the effective resistance is found out by finding out the effective resistance across the capacitor as the Thevenin's resistance between the two terminals. That means, first, short circuit all the voltage sources and open circuit all the current sources, and find out the resistance. That resistance will come in the denominator.

So, we have the Thevenin's voltage here as R i by R i plus R s. So effectively, we have R i by R i plus R s. This we had got earlier also, was the attenuation of this V s when it comes here as V i. Apart from this, we have 1 plus sC into R equivalent; this is R, which is R i R s divided by R i plus R s.

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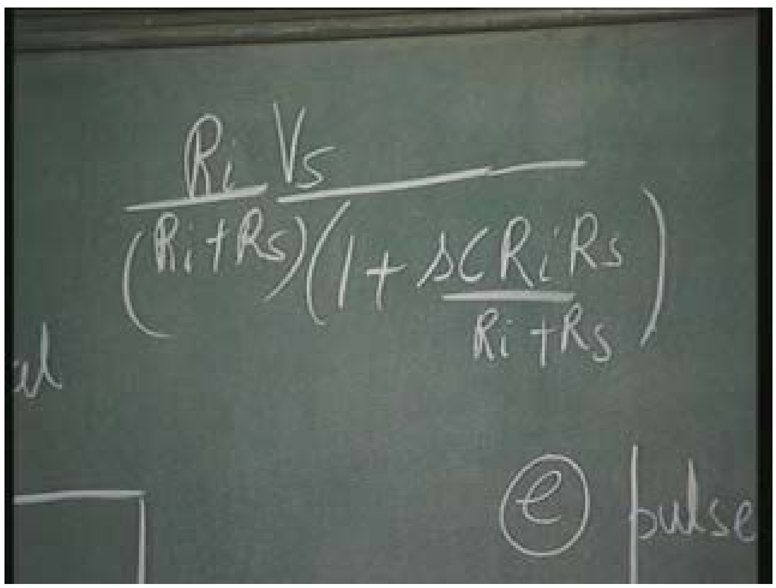

So, this is what is called as a transfer function between V i and V s. This, please remember; in the earlier evaluation, this factor was not at all there. It was only R i by R i plus R s into V s. Now, a new factor of attenuation has come because of capacitor.

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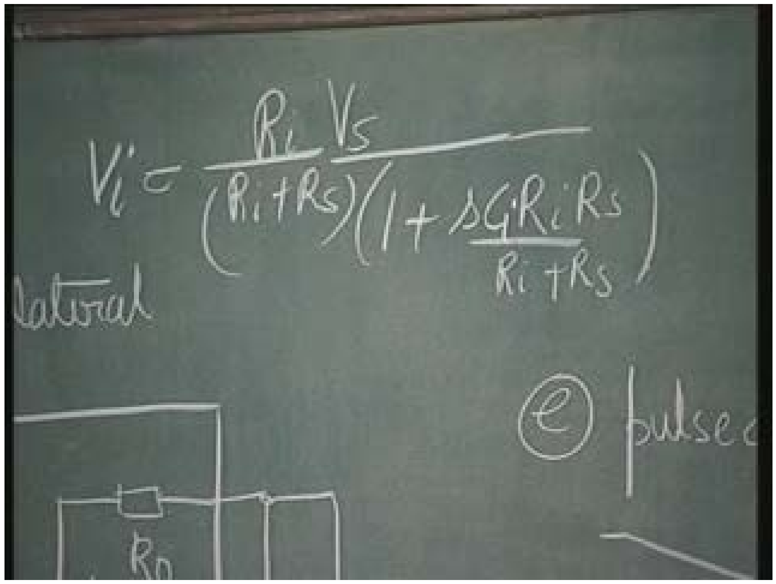

And this is frequency dependent; C is equal to C i. This is frequency dependent and therefore the V i decreases as frequency increases. Then, this voltage is going to appear here as K times V i. So, V i is this; K times V i is this; so that gets, remains unaffected.

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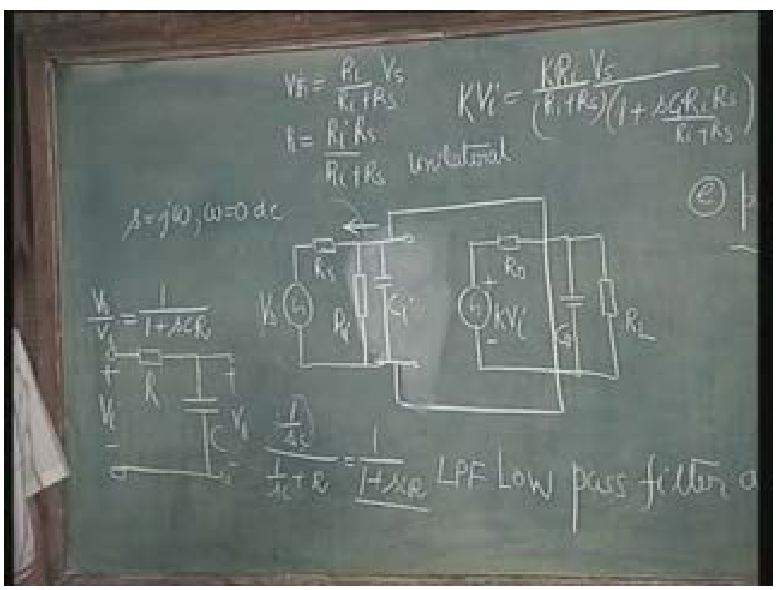

Now, I have to find out the voltage V naught ultimately. How do I get V naught? V naught is across C naught. By a similar argument, I would leave this as an exercise for you; we can treat this as a source in series with the resistance R naught shunted by a capacitance C naught across R L.

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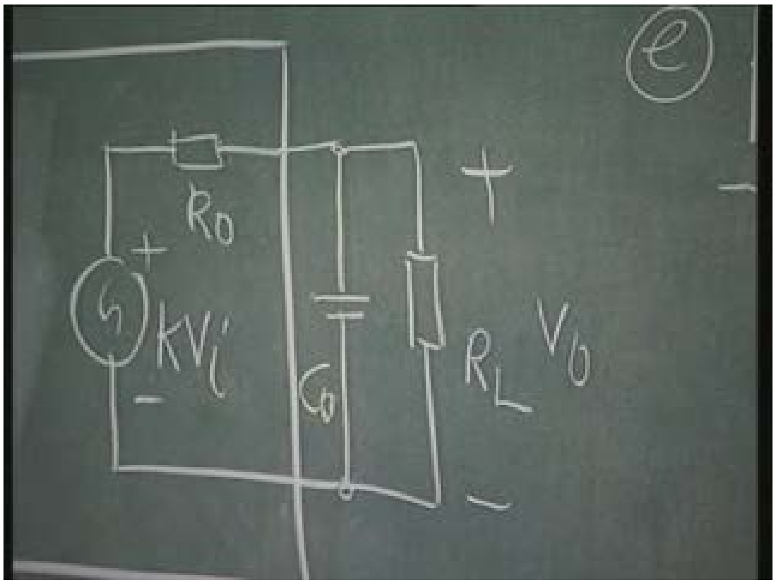

So, this situation is exactly similar to this. So, you can again convert this into a Thevenin’s equivalent where the equivalent resistance is R L parallel R naught; and the capacitance is C naught, and find out the voltage here. So, without doing any analysis, I can do that. It is going to be equal to R L by R L plus R naught, the low frequency thing, R L by R L plus R naught, times K V i; this into 1 plus sC naught, R L R naught divided by R L plus R naught.

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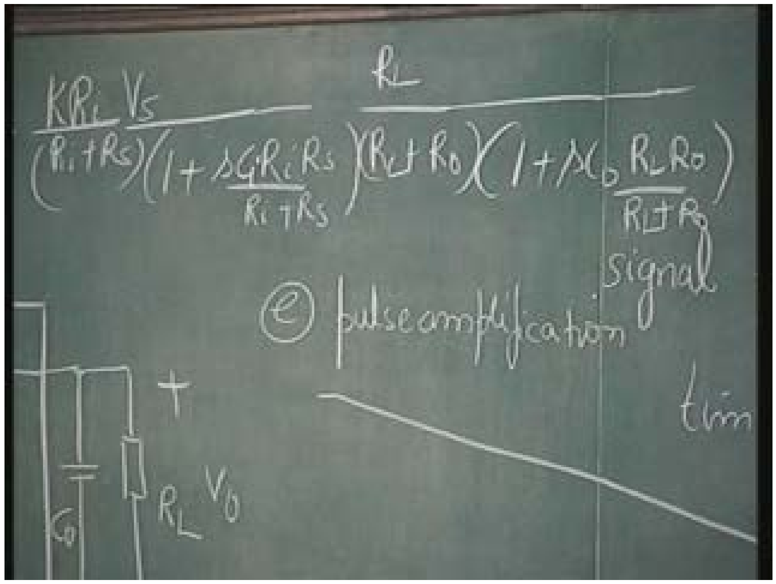

I am writing it straightaway because we know that it is exactly similar in nature, except that C i is replaced by C naught; R i is replaced by R L; R s is replaced by R naught and V s is replaced by K times V i okay. So, the analysis is similar; and therefore it will come out with another attenuation like this. So, the total gain is going to be, this whole thing is going to be, equal to V naught.

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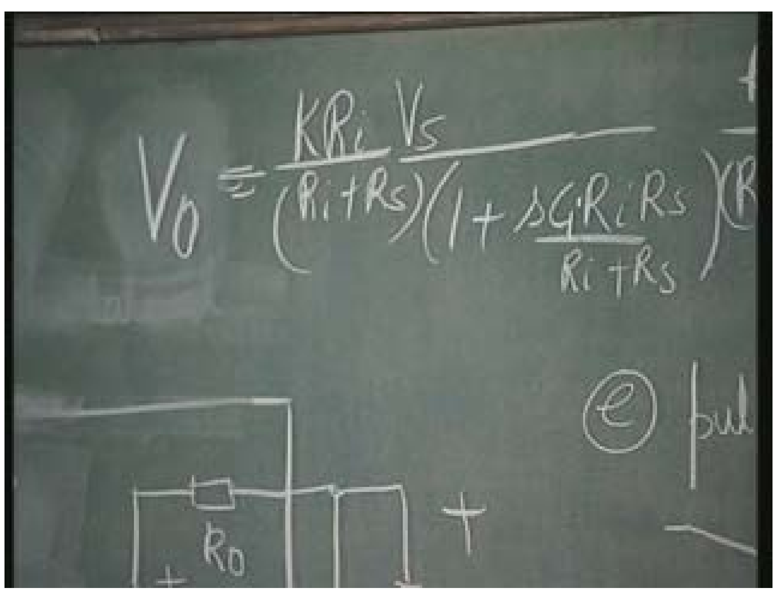

So, what has happened? Earlier, we know that V naught over V s was equal to simply K times R i by R i plus R s into R L by R L plus R naught. This was the earlier expression. You can refer to your notes and verify this was our earlier expression for voltage gain V naught over V s. Now, that gets modified by 1 plus sC i R i R s by R i plus R s. This is called input time constant.

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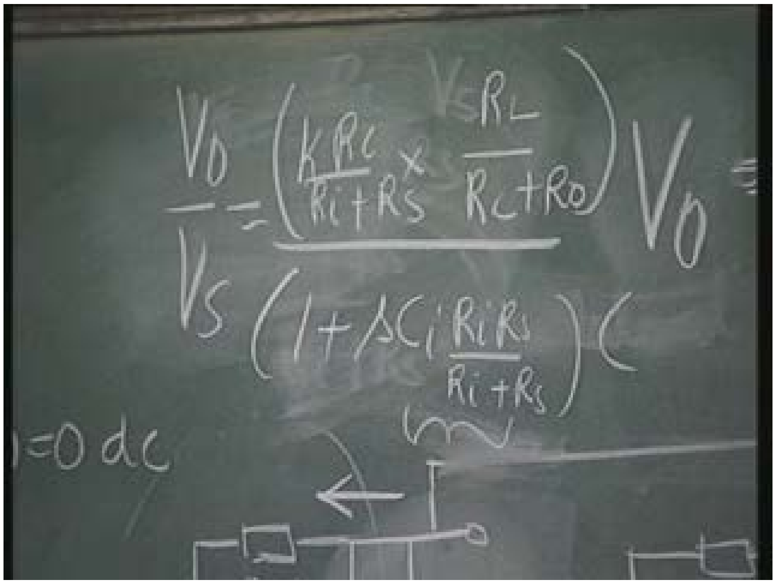

C i is the input capacitor; R i R s by R i plus R s is the effective resistance across the capacitor. So, this is called the input time constant; we call this as tau input time constant.

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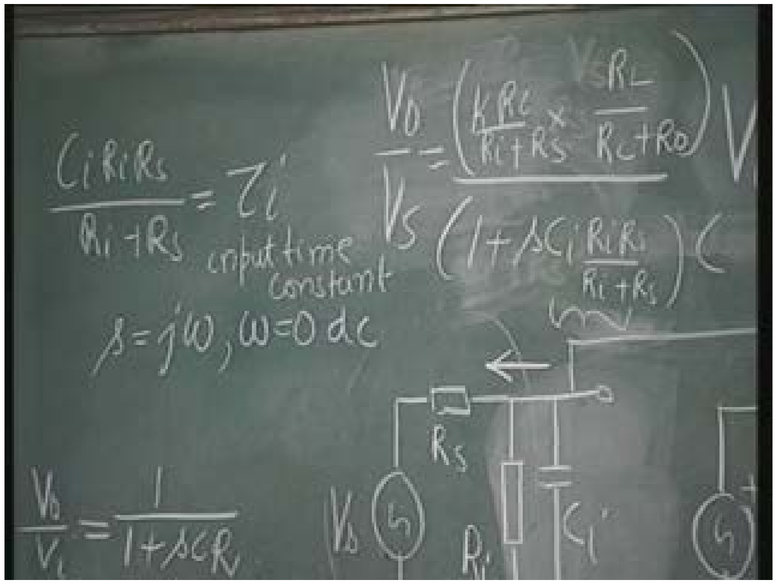

So, we can instead of keeping on writing this, we will put it as simply input time constant tau i. C into R is the dimension of time.

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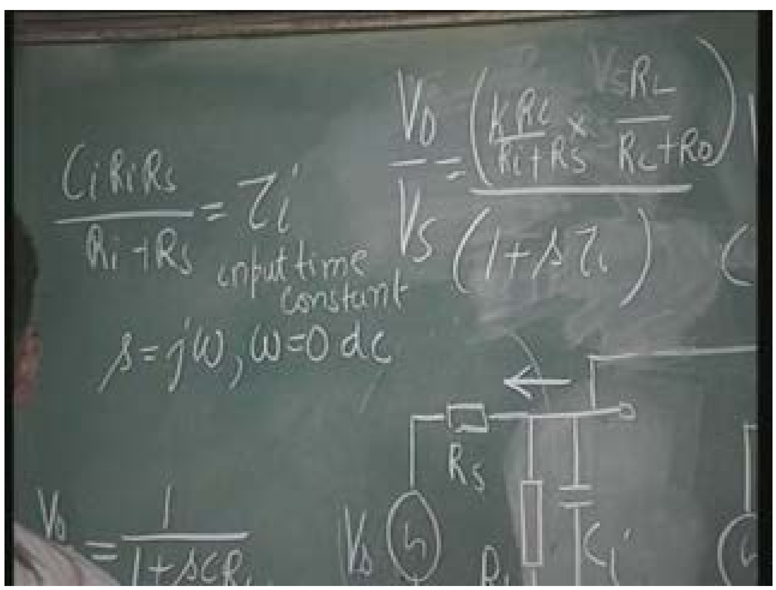

So, this one... the other one is therefore called the output time constant; and output time constant is tau naught, which is C naught R naught R L by R naught plus R L.

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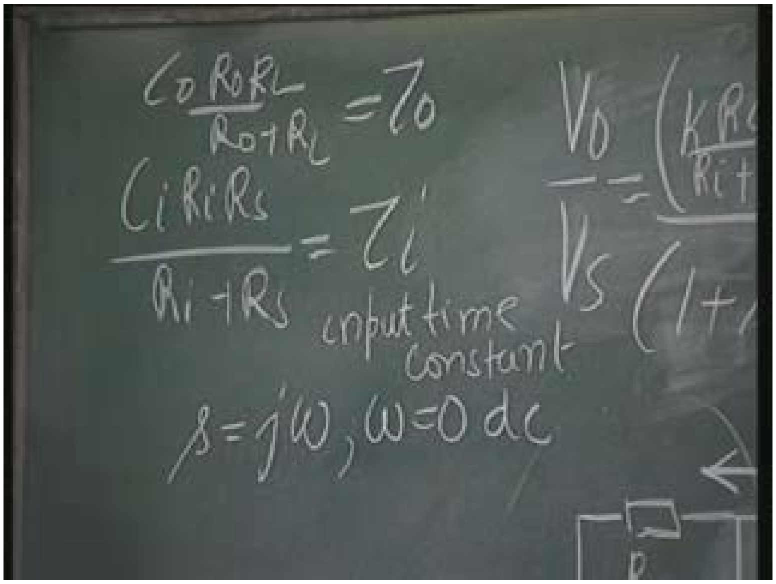

For any amplifier, the input time constant and output time constants are always the same as what is indicated here. Whether it is a FET amplifier, or an operational amplifier, or a bipolar junction transistor amplifier, these definitions remain the same; input time constant and output time constant bring about degradation in performance of the amplifier at higher frequencies. This gain is the low frequency gain and these are the high frequency attenuation factors, tau i and tau naught. So, tau naught is the output time constant.

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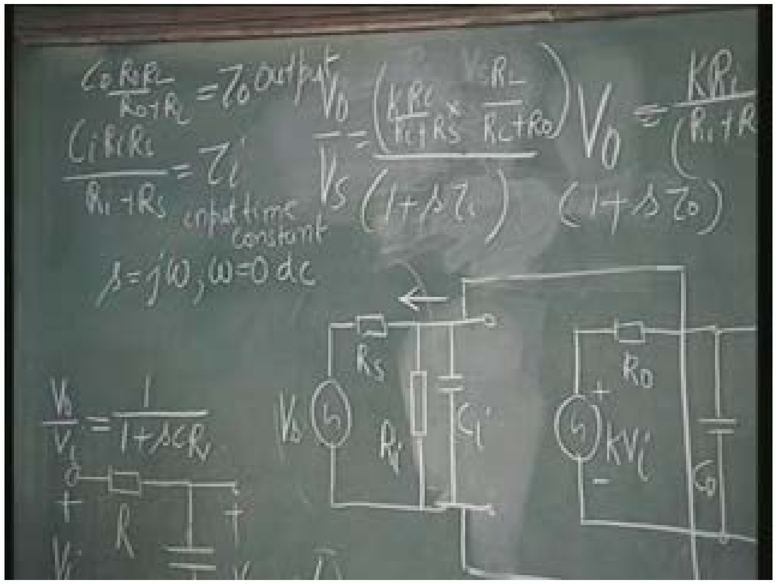

Now, summarizing what we had just discussed previously, the dc gain K naught, which is independent of frequencies; whatever term that is independent of frequency that we call as dc gain, V naught over V s. So, R i by R i plus R s, the attenuation constant at the input into open loop gain K into R L by R L plus R naught, attenuation constant at the output. Attenuation at the input, attenuation at the output and the open loop gain, overall gain, is therefore determined by this.

Just by looking at the amplifier circuit, you should be able to evaluate the overall gain without really putting down any equations. Similarly, the time constant tau i and tau naught, if they are known, tau i being the input time constant, tau naught being the output time constant, tau i is defined as C i into effective resistance across the capacitor at the input; and tau naught is C naught into effective resistance across the capacitor at the output.

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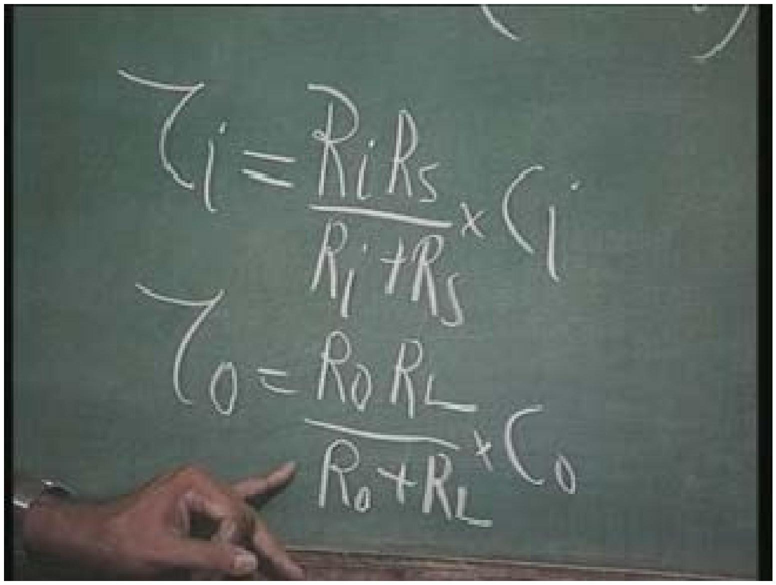

So, if you know this, you can straightaway write down the transfer function V naught over V s, without really solving any equation. That is what you should practice. K naught divided by 1 plus s tau i into 1 plus s tau naught.

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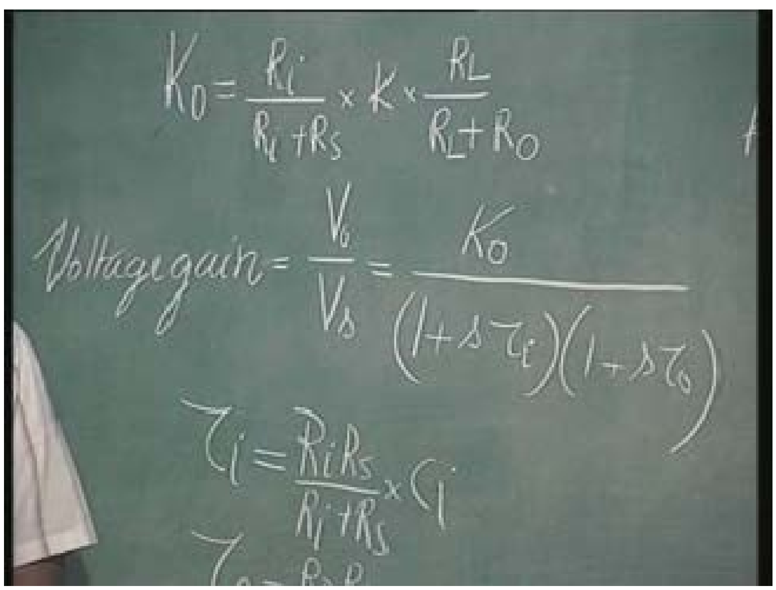

It is always going to be the transfer function in terms of tau i and tau naught, irrespective of the amplifier configuration. Whether it is a voltage controlled voltage source, current controlled current source, or any of the other two types, as long as it is non-ideal, this is the way it is going to be defined. So, this is a general term.

Now, let us see how this looks like. This has made the amplifier frequency dependent and that frequency dependent, that dependence, is plotted here in these two diagrams. These are, this is called, popularly known as Bode's plot.

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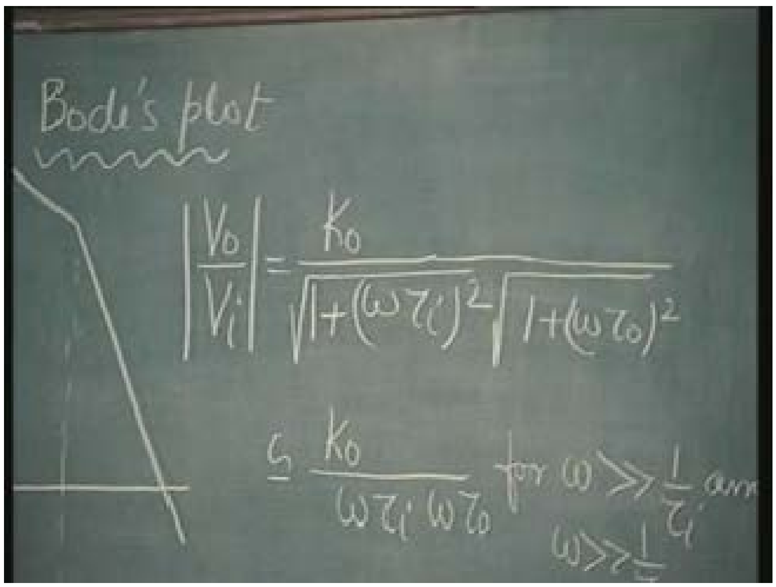

You must have come across this in your controls. However, it is nothing but magnitude of V naught over V i plotted as a function of omega, phase of V naught over V i plotted as a function of omega. This is magnitude of V naught over V i which is nothing but K naught divided by root of 1 plus omega tau i whole square, where s is replaced by j omega, and then you find out the magnitude.

So, 1 plus omega tau i whole square, root of that; into, 1 plus omega tau naught whole square, root of that. That is the magnitude function. That magnitude function, plotted as a function of omega. Now, how is it plotted? It is plotted as 20 log of this. So actually, what you are going to do is, 20 log of this is plotted so that, this is in terms of decibels.

So, this is what we have earlier also indicated. 20 log to the base 10 of V naught over V i. That means, this will be in terms of decibels, so many decibels. Suppose K naught is 100; then, this is going to be 20 log to the base 10 100, which is nothing but 40 decibels. So, this will start with 40 decibels of gain.

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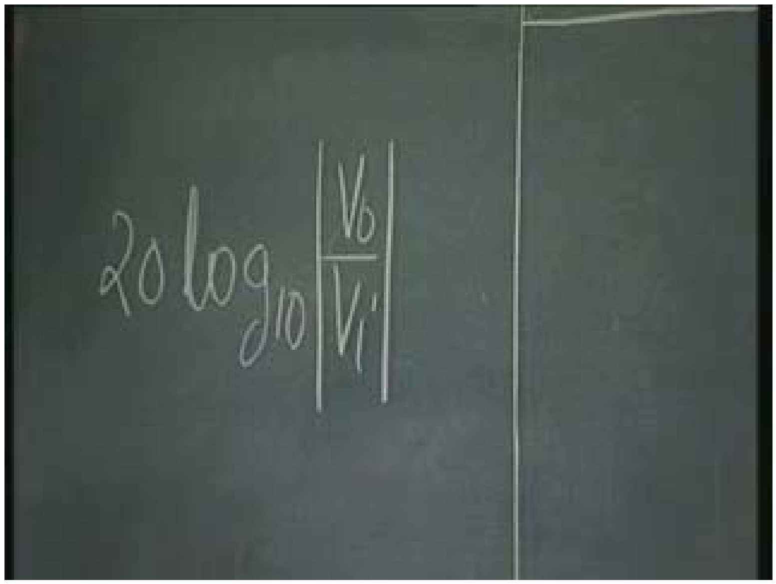

So, the gain is reducing. That means it is falling here. This fall is indicated here as an asymptote, asymptotic fall. How do you get that? For omega much greater than 1 over tau i, this factor is very dominant compared to 1; so you can ignore 1. So, this whole thing becomes omega into tau i. It is inversely proportional to frequency omega here.

This factor, let us consider, is not coming into picture now. That means it is still far away from this omega.

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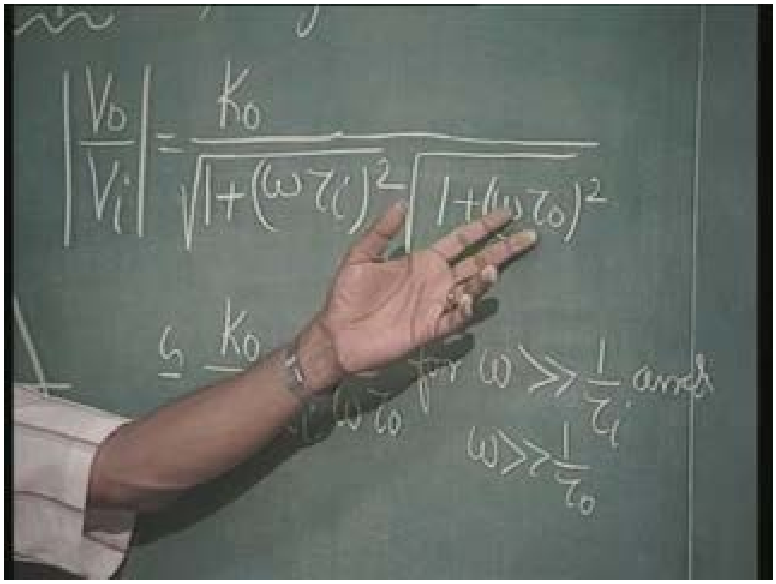

Then, this is small compared to 1. Only this has become very large compared to 1.

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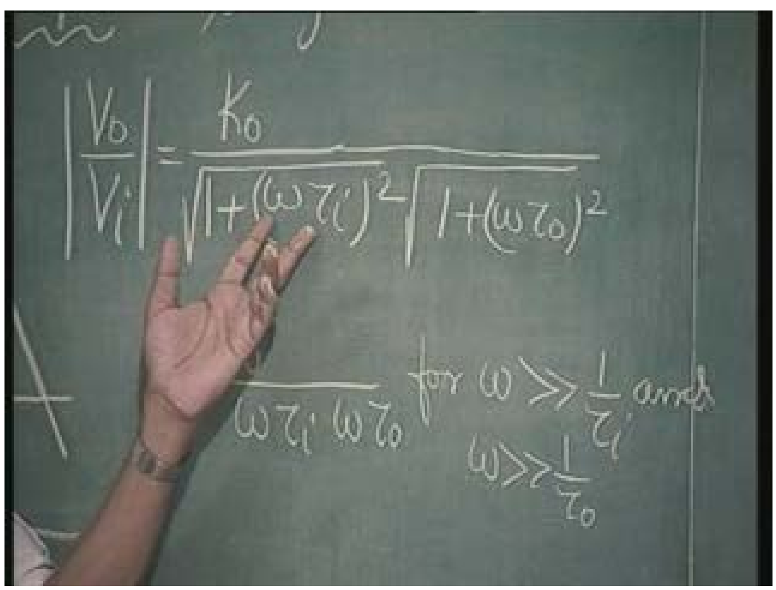

In this range therefore, we can say that this is dominant; time constant tau i is said to be dominant. tau i is much greater than tau naught, let us take.

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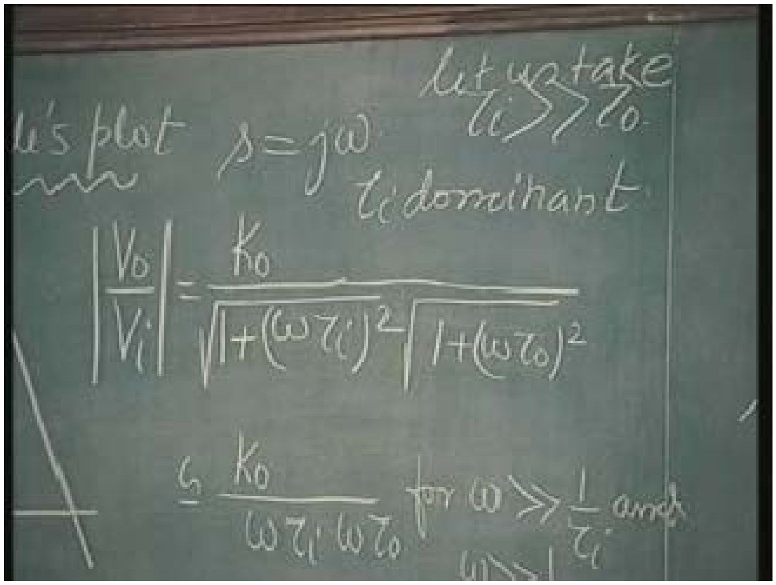

This may not be the case; but if we take tau i much greater than tau naught, then I can explain to you what exactly happens, because each of these time constants. They are coming almost independently. tau i is much greater than tau naught. First, tau i makes its appearance; omega tau i becomes much greater than 1. So, this is K naught by omega tau i. This factor is very negligible; say 1. So, this is k naught by omega tau i. It is inversely proportional to omega.

If you take 20 log of this factor, then, you can call this as an attenuation, at 20 decibels per decade.

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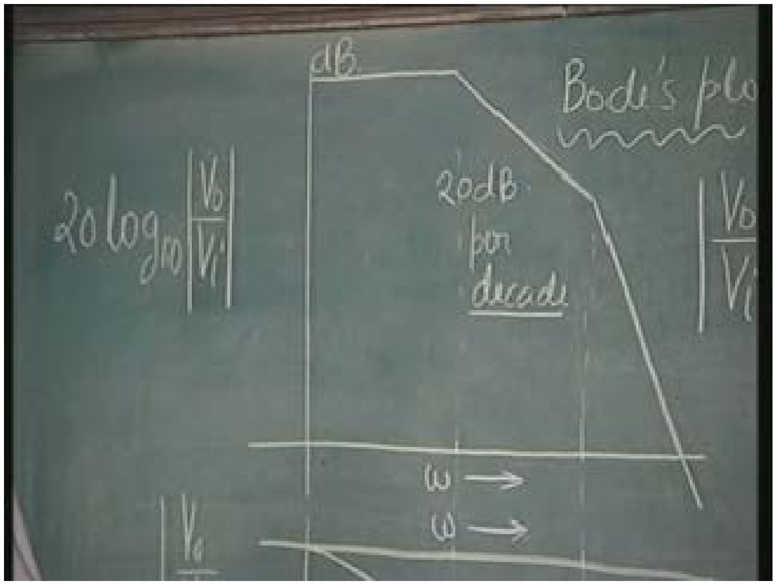

This term, this is a commonly used term. The attenuation is 20 decibels per decade. How? We know that K naught by omega tau i is the attenuation in this range and let omega change by a factor of decade; that means, 10. Then, the attenuation from whatever frequency you are starting and whatever frequency you are going, if it is a decade apart, then the attenuation is 20 decibels because it is 20 log, 1 over 10, 20 log 1 over 10 it becomes, which is minus 20 decibels per decade.

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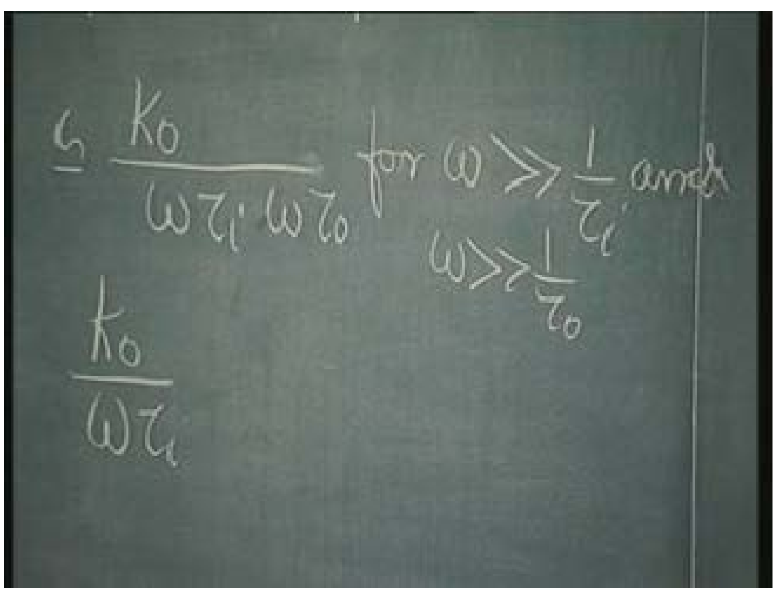

So, due to one corner frequency which is dominant, the attenuation is 20 decibels per decade. This is always the case. Irrespective of, again any specific amplifier configuration, if one time constant becomes dominant, we can make a statement, general statement that there is going to be an attenuation of 20 decibels per decade. Or, this is also called as 12 decibel, that is, actually, we are calling, instead of decibels per decade, we will also have a terminology called octave. What is octave? A factor of 2. So, 20 log 1 over 2, which is, minus 20 log 2. Log 2 is point 3. 20 log 2 is 6 decibels. So, you have 6, minus 6, minus 20, decibels per octave.

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As electronic engineers, this terminology you must never forget. Because of one frequency dependence, because of one time constant, the amplifier is going to have an attenuation of, always, any amplifier is going to have an attenuation of, 20 decibels per decade or 6 decibels per octave. If another time constant comes, then, it will have a further attenuation of 20 decibels per decade or total attenuation of 40 decibels per decade or 12 decibels per octave.

So, N number of time constants will cause 20 into N decibels of attenuation per decade or 6 into N decibels of attenuation per octave. This is universal. So, you can therefore see how attenuation occurs in the so called out of the pass band. This is called the pass band. This is the band of frequencies which is permitted to pass the amplifier without much of an attenuation, with respect to frequency. This is the pass band. This is the corner frequency. These are all called corner frequencies. These asymptotes correspond to this omega i, 1 over omega; this is 1 over omega square.

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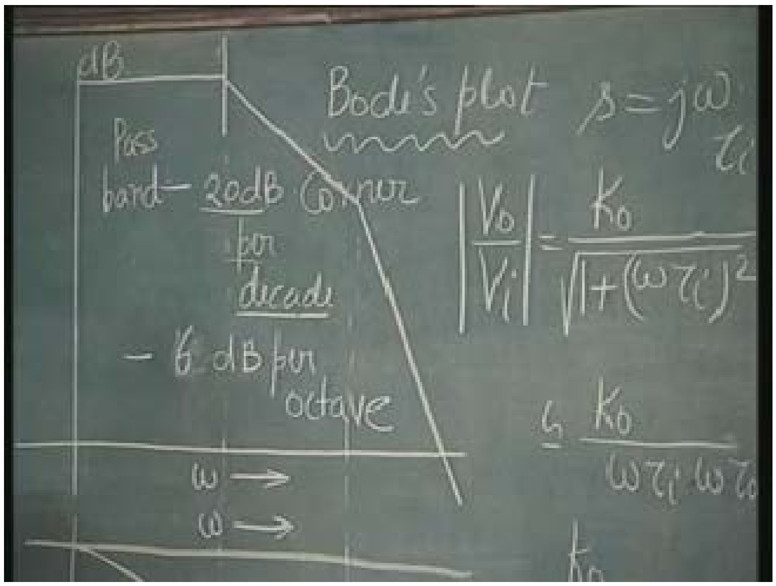

So, this is 20 decibels per decade; this is 40 decibels per decade. There is next, another one coming that will be 60. But here, it is a two time constant system; so it can only cause an attenuation of 40 decibels per decade.

Now, something regarding the ((phase shift of asymptote Refer Slide Time: 35:25)). Therefore, these non-idealities come into picture in any amplifier. This is also a performance factor, which is as important as input resistance, output resistance and gain. So, this is one of another performance factors. It tells us, up to what frequency it can be used. This is called the upper cut off frequency. This is the first corner frequency in control terminology; or, this is also called upper cut off frequency, upper cut off frequency.

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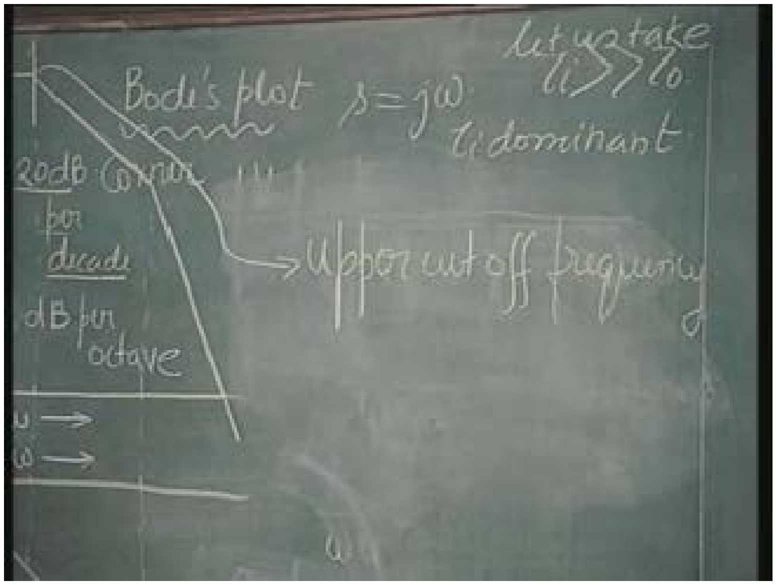

What is this? In this case, it is equal to, omega equal to, 1 over tau i, exactly. This corner frequency corresponds to omega equal to 1 over tau i; and this corner frequency is going to be omega equal to 1 over tau naught. As long as tau i is far away, 1 over tau i is far away from 1 over tau naught, this is what happens. Otherwise, they will be actually related to one another; upper cut off and the other cut off.

Now, upper cut off frequency is very important; it determines the band width of usage. So, the bandwidth of usage of this amplifier, for example, where tau i is the dominant time constant, is equal to 1 over tau i. So, bandwidth is equal to 1 over tau i.

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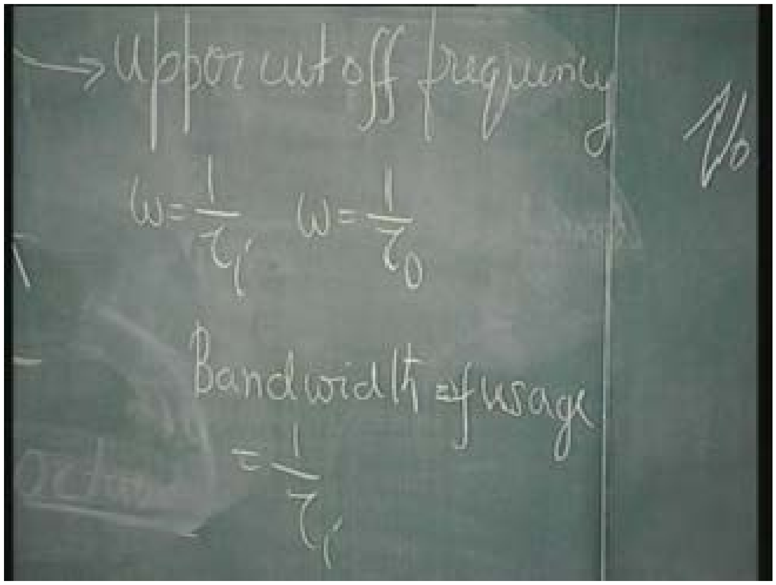

What it simply means is, if tau i is dominant, this can be ignored. If tau i is much greater than tau naught, this can be ignored because this is of no significance, in the frequency range of interest to us.

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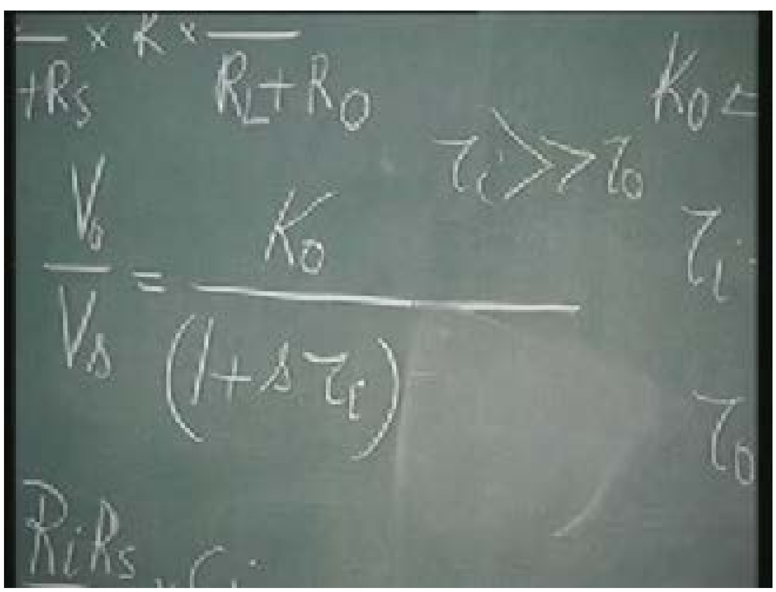

Why? What is the frequency range of interest to us? It is this pass band. That is the frequency range of interest to us. In that frequency range, it has no influence. So, this is a single time constant system. Is this clear? Dominantly determined by tau i; so this is a single time constant system. If both the tau i and tau naught were of same order, then, this is a second order system. If this is negligible, as negligible effect in the pass band, then this is called, this is approximated as a first order system.

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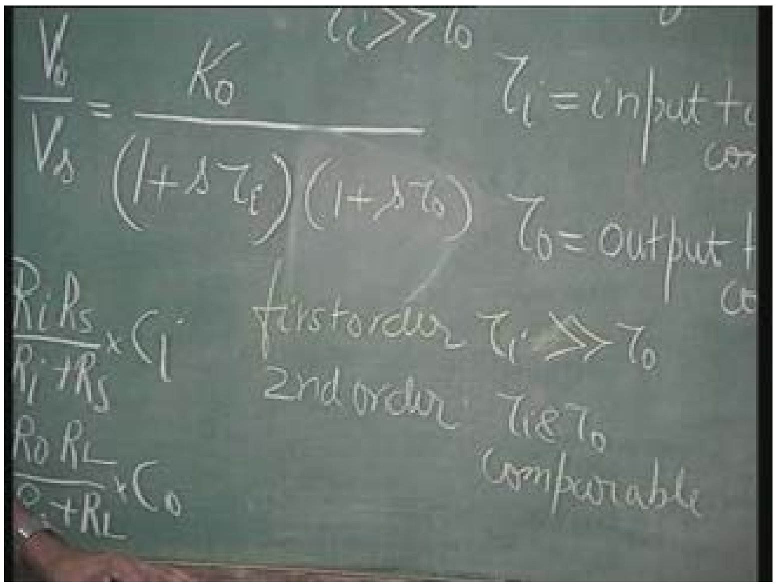

Is this clear – definition? This is a first order system if tau i is much greater than tau naught. This is a second order system if tau i and tau naught are comparable to one another. If tau i is much greater than tau naught, then the bandwidth of this system is 1 over tau i; it is called the corner frequency of the system, first corner frequency of the system. It is also called upper 3 dB point.

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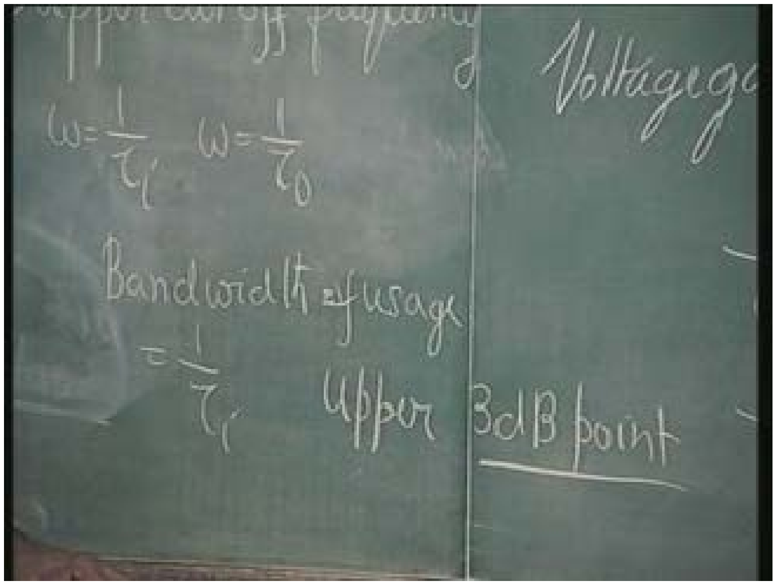

Why this? Let us understand that. If this is negligible, then, this is the one that fixes up the attenuation; and s is equal to j omega, you are going to put.

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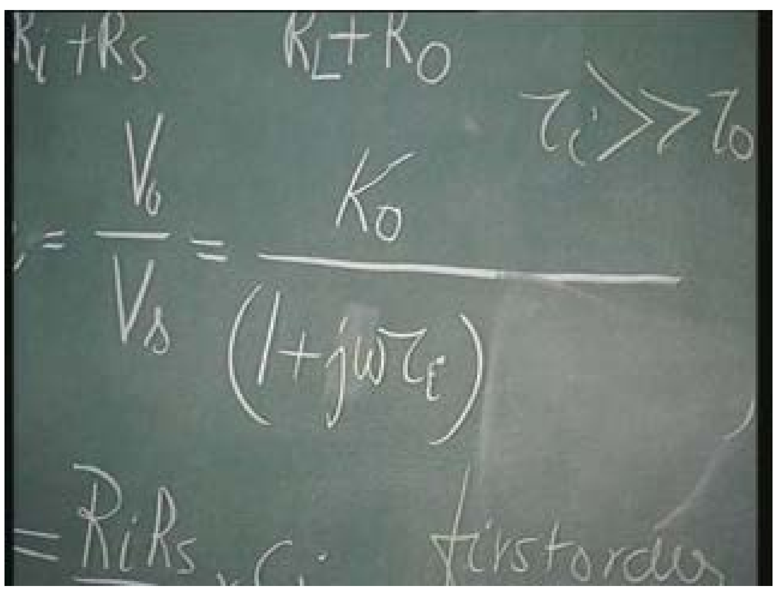

And therefore, the magnitude function for this is going to be root of 1 plus omega square tau i square. Say, omega equal to omega over tau i. This factor becomes equal to 1.

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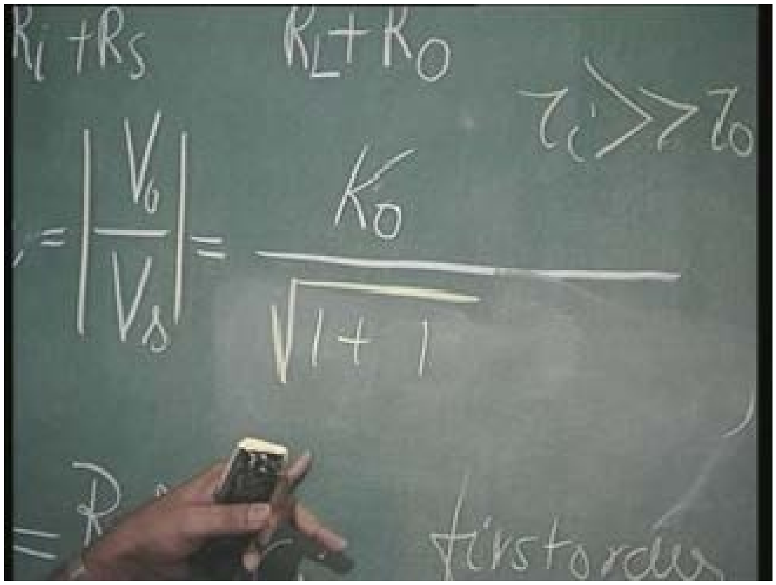

So, this factor becomes K naught divided by root 2. And, if you compare it with K naught, it has reduced by 1 over root 2. It is therefore 20 log 1 over root 2, which is 10 log 1 over 2 or minus 10 log 2 which is 3 dB, minus 3 dB. So, this is called upper 3 dB point. So, this is equal to K naught by root 2.

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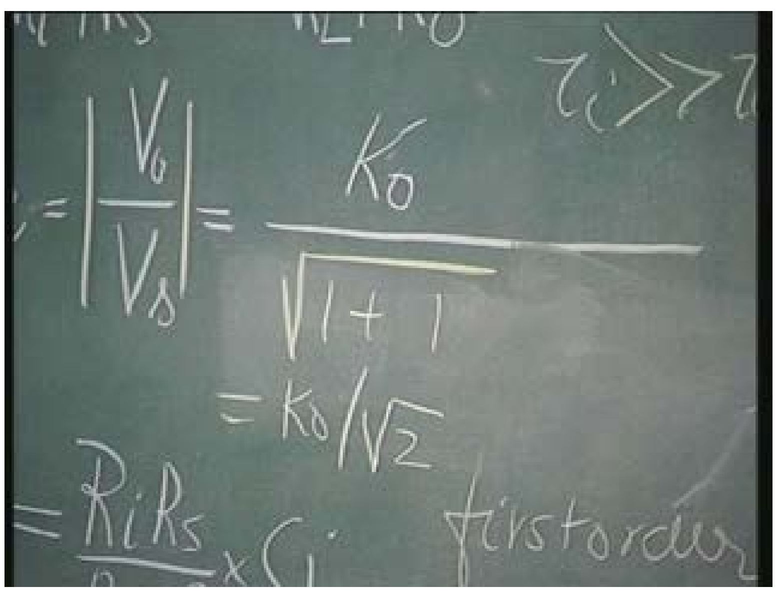

Or, this corner point, the attenuation, actual attenuation curve will be going like this. So here, it will be suffering an actual attenuation of 3 decibels.

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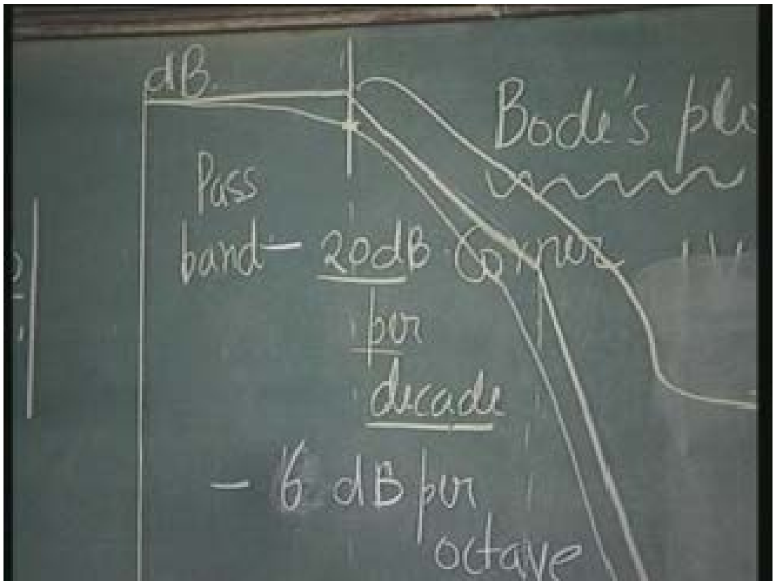

At every corner frequency, it will suffer an additional attenuation of 3 decibels. So, at this point, it would definitely suffer, may be, an additional attenuation of 3 decibels, apart from whatever it has further suffered due to the first corner frequency. So, these are the important definitions. If voltage gain reduces by 1 over root 2, power gain reduces by another factor of 1 over root 2. It is square; so, power gain is halved. This is also called upper half power point.

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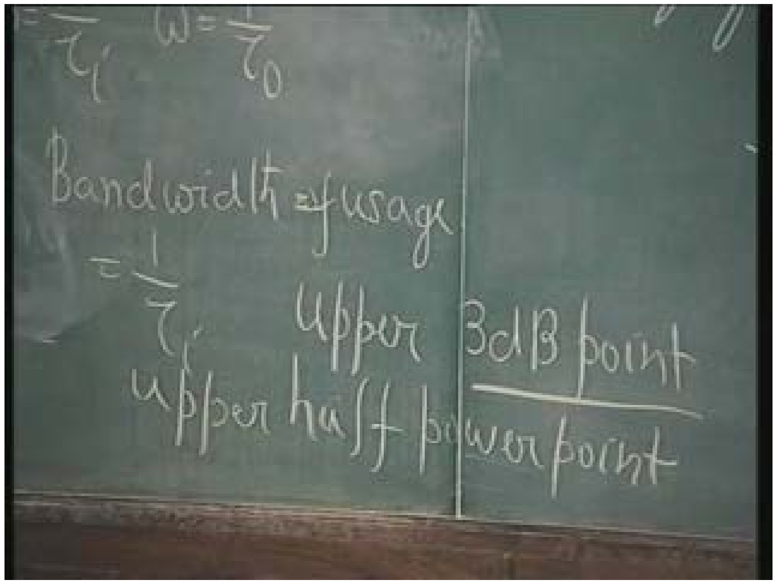

Now, I am giving you all these definitions which are involved for the same thing. Upper half power point is same as upper 3 dB point is same as what? - first corner frequency. All these things are same things, defined in different ways. This is in terms of voltage ratio; this is in terms of power. So, this is important in estimating the useful frequency range of other amplifier. Any other point would have also been chosen; but they have conveniently chosen the half power point for reference. Therefore, this corresponds to half power point.

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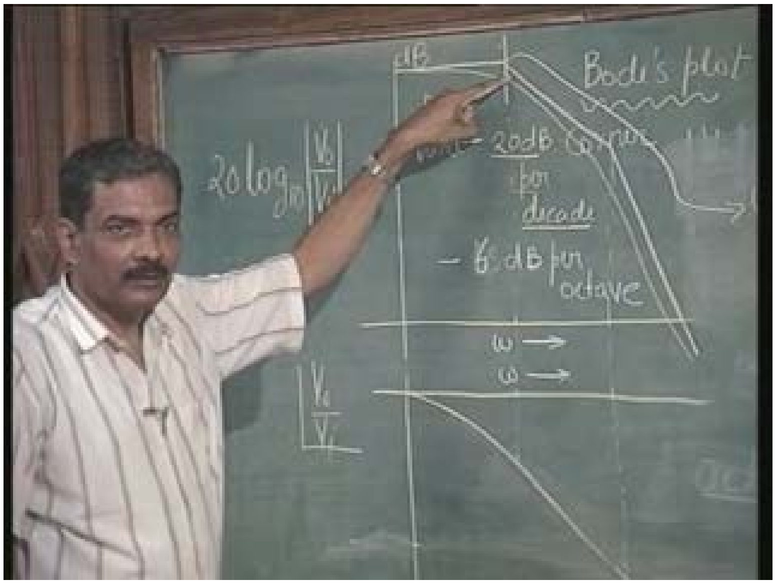

And, the useful range of bandwidth of your amplifier is up to the upper cut off frequency, first upper cut off frequency really; so, first corner frequency. If this bandwidth is of the order of, let us say, tens of Kilohertz, then it is audio amplifier; if this bandwidth is of the order of megahertz, then it is video amplifier.

So, that is why, in classifying the amplifier, it is important you understand how this bandwidth comes about. This bandwidth comes about because of shunt capacitors which are unavoidable in circuits. And therefore, in order to maintain the bandwidth of an amplifier very high, we have to make these time constants very low. It is obvious.

This also gives us design features for wide band amplifiers. In order to make these time constants very low, we have to have obviously C i very low, C naught very low; also, we have to have R i and R s very low. This is important.

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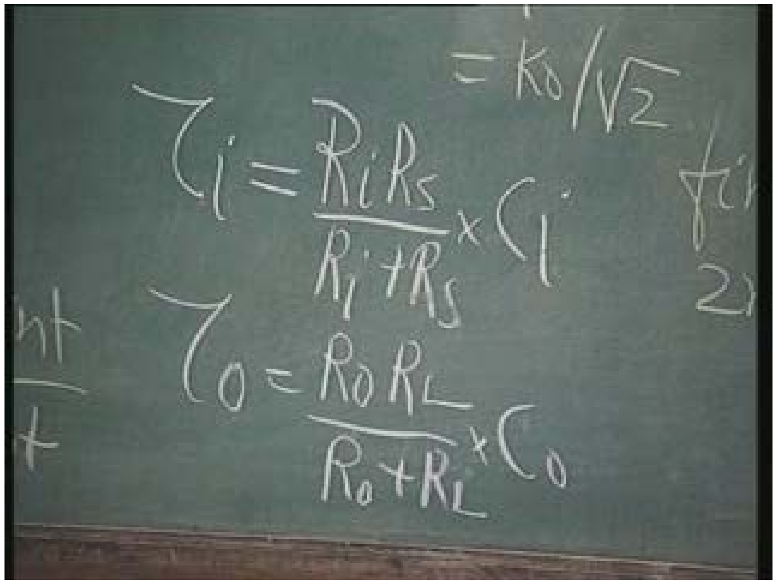

R i and R s also must be very low in order to have... or R naught and R L; any one of this. Either R i or R s should be low in this; here, either R naught or R L should be low. So, these are important in designing wide band amplifiers. So, wide band amplifiers also are called pulse amplifiers. So, even if you are designing a pulsed amplifier, same design features are valid. You have to make the capacitors very low. You have to make the... either source resistance or input resistance very low. If you make source resistance very low, you are calling it voltage source driven. If R i is made very low. it is current controlled. So, either it can be voltage controlled or current controlled; either it can be a voltage source or current source.

As long as you are using ideal amplifiers which are driven very nicely, then, you are going to achieve wide band for your amplification. Therefore, this is one of the important performance factors of an amplifier; the band width of an amplifier; and that is determined by this Bode’s plot.

Now, the phase information. This is also important. How do you get the phase? In this expression that we have, 1 plus s tau i, 1 plus s tau naught... As frequency increases, the phase lag occurs because, both are in the denominator. So, the phase is, tan inverse. That is, phi, phase lag, tan inverse omega tau i plus tan inverse omega tau naught. That is the phase lag associated with this transfer function. At very low frequencies, there is no phase lag; so, this is going to be zero, phi. Starting with zero, gradually there is going to be phase lag. At tau i, tau i being dominant, we have omega tau i equal to 1. It becomes 1 plus j; 1 plus j means how much? A phase shift of 45 degrees. So, around this point, we have a phase shift, phase lag of 45 degrees.

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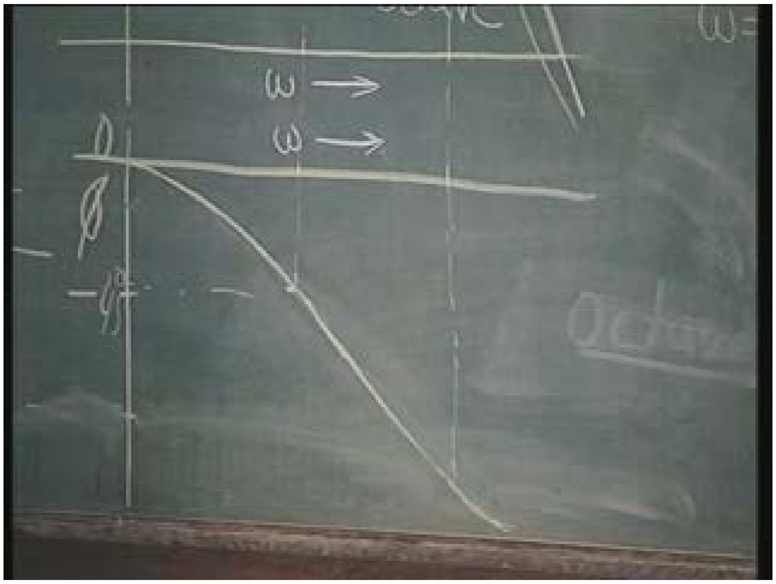

Then, as this progresses, the dominant time constant would have already contributed to your full phase because omega tau i becomes dominant compared to 1. That means, it is phase shift of 90 degrees it would have given. Then, when we come to other frequency, omega equal to 1 over tau naught is this; omega equal to 1 over tau naught is this; at this frequency, additional phase of 45 degrees can be given. So, we have a phase shift of minus 135 degrees. So, it is going from 45 degrees at one corner frequency to minus 135 degrees at the next corner frequency.

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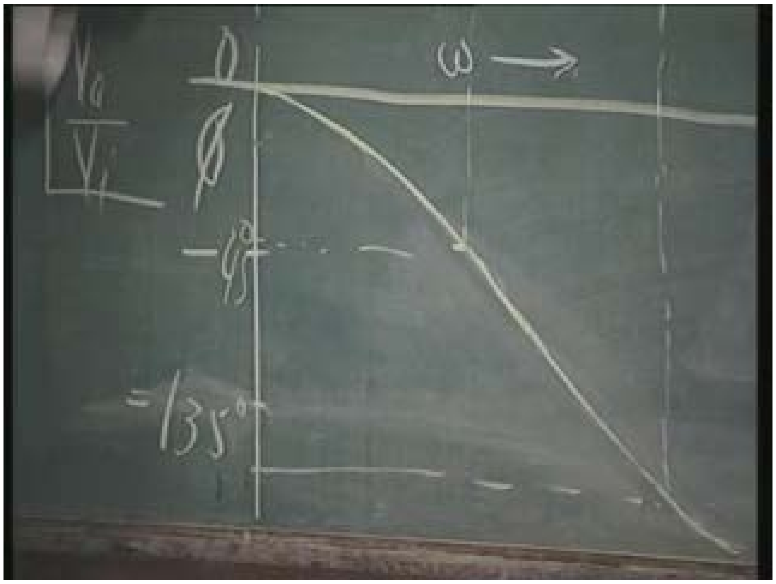

Ultimately, it will go to... both will contribute to a phase shift of 90 degrees, and it will go to 180 degrees, at infinite frequency. So, this is capable of going to a phase lag of 180 degree only at infinite frequency. So, this is the phase plot of the circuit; together, these plots are called Bode's plot. These are important in characterizing amplifier very well.

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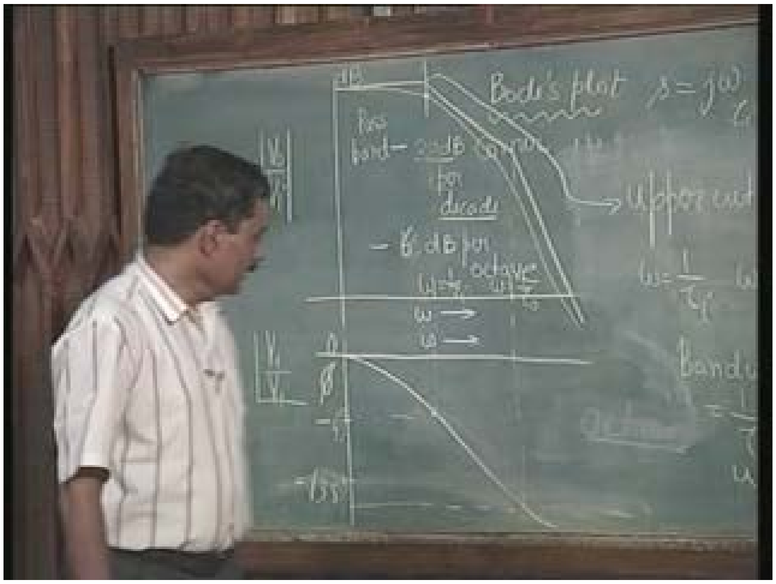

So, both these distortions: the magnitude distortion as well as the phase distortion, together contributes to the distortion signals; different frequency components get subjected to different phase shifts and therefore there is a distortion in the signal. Therefore, it is required that we restrict our field of operation within the pass band.

Now, as far as tuned amplifiers are concerned, basically, the load is selected in such a manner that this particular frequency response characteristic is not like this - flat from the low frequency end, coming down; it is starting with zero, reaches a peak at certain point and comes down like this. So, the tuned amplifier characteristic is different from these wide band amplifiers, or, low frequency amplifiers.