Electronics for Analog Signal Processing - I
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Lecture - 16
Two Port Analysis

In yesterday's class, we made use of the two port network theory to evaluate the performance factors of amplifiers, such as, input impedance, output impedance, voltage gain, current gain and power gain.

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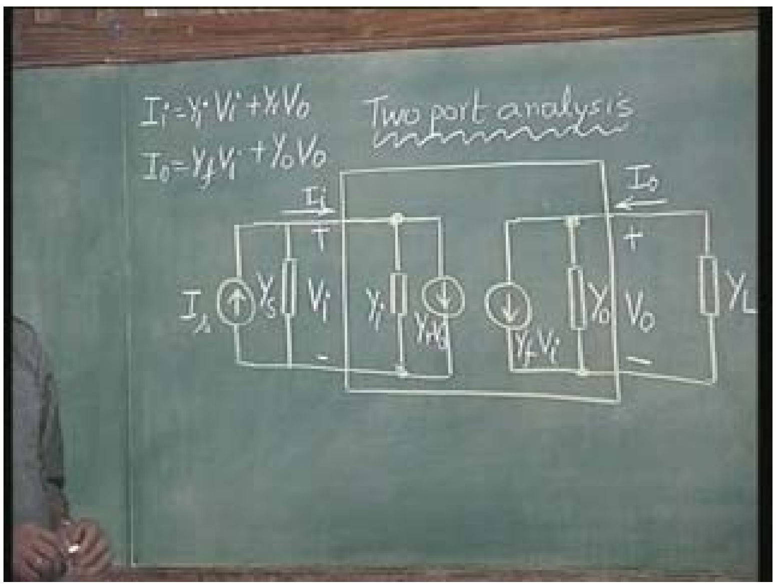

These are the important factors, performance factors, associated with any amplifier. Taking for example, Y parameter, I had shown you how to evaluate the input impedance and asked you to evaluate the output impedance; and I evaluated the voltage gain, asked you to evaluate the current gain and power gain. Today, let us see whether you have really understood this. In case you have any difficulty in evaluating this, we would work out the whole thing for the Y parameter case now.

I would request you to perform the same calculations for all other parameters in almost identical fashion and see what these input impedance, output impedance and power gain, voltage gain, current gain are in the respective parameters. So, I would like you to concentrate on the method that is adopted here. The same method must be adopted for the rest of the three parameters.

So, first, let us see how we can evaluate the input impedance. So, we take this equation I i; and Y i is the self-impedance at the input; this multiplied by V i and Y r; and you have to replace this V naught by something that is dependent upon V i so that we can find out the input impedance, which is Z i; Z in, which is one over Y in; and Y in is I i by V i.

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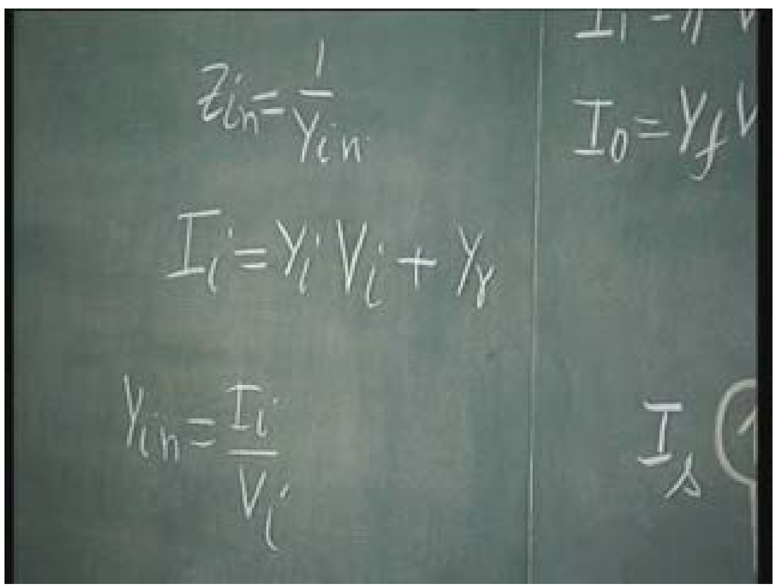

This is the input impedance seen from here. In fact, if Y r is zero, this is same as Y i. If Y r is not zero, this is Y r into V naught; and this V naught has to be replaced in terms of V i. So, it is necessary for us to evaluate and find out what is the relationship with V naught and V i. That we can get from the second equation.

We know that I naught, I naught is the output current here and I naught is equal to V naught into Y L. But the current then will flow this way; so minus V naught into Y L. So, I naught in any of these circuits is always equal to minus V naught into Y L. This is always the case. I naught is known in terms of V naught and load admittance.

So, because this is assumed as plus, minus, the current would have flown this way and I naught is assumed to be opposite, we put the negative sign. So, substitute this I naught in the second equation. So, we have minus V naught Y L equals Y f V i plus Y naught V naught.

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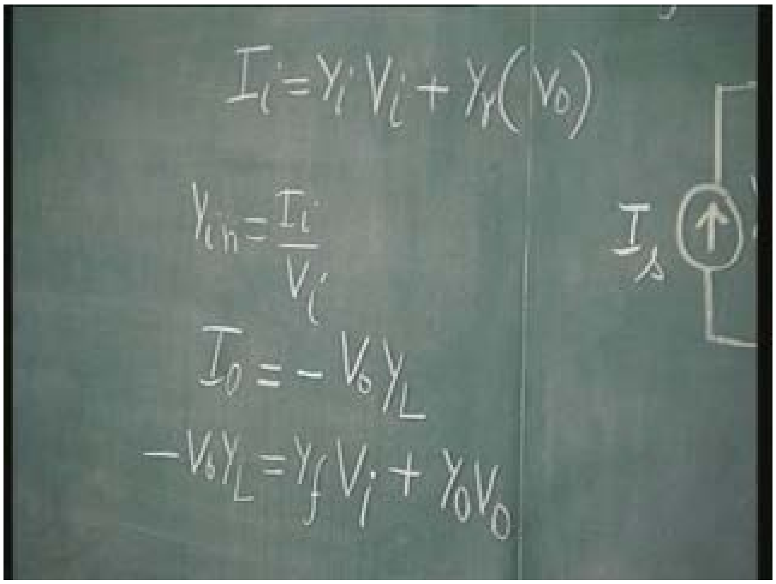

So, this equation is the relationship between V naught and V i as V naught over V i is nothing but minus Y f divided by Y naught plus Y L.

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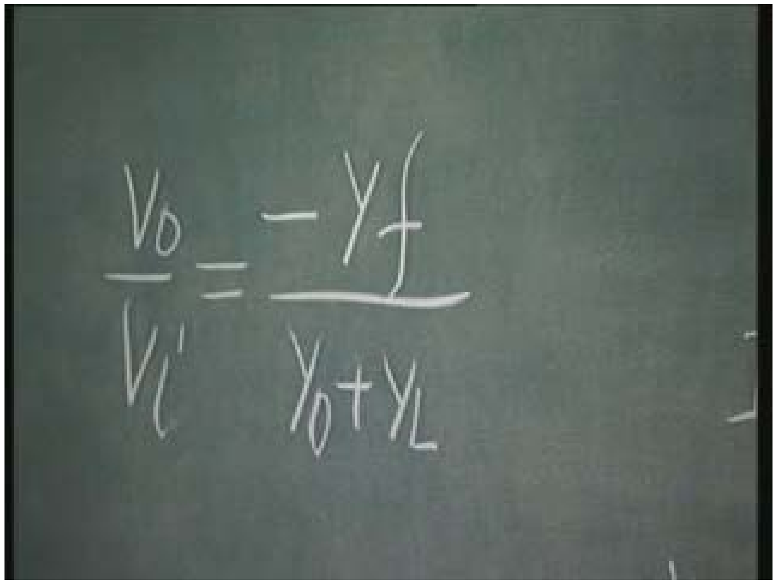

This, in the last class, we had very simply evaluated from this circuit itself. Y f into V i is the current in this.

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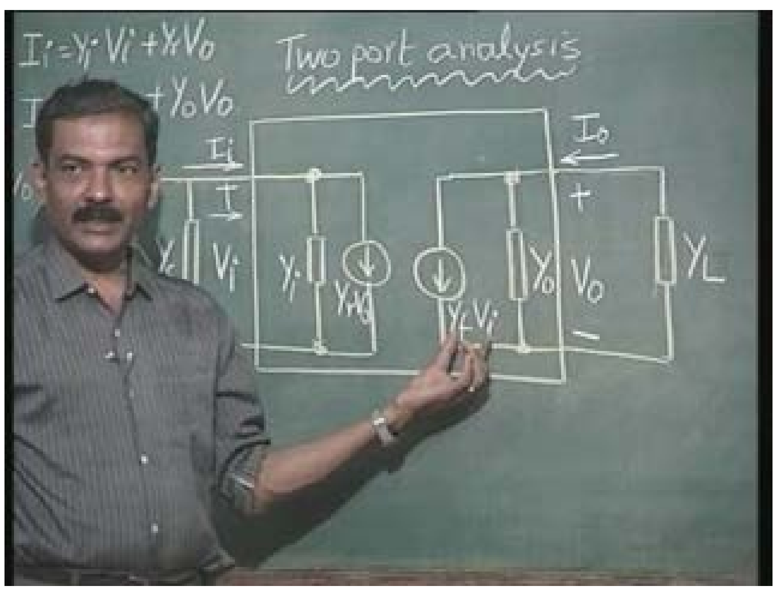

This current will flow through the total admittance which is Y naught plus Y L; the resultant voltage therefore has to be Y f into V i into 1 over Y naught plus Y L with a negative sign.

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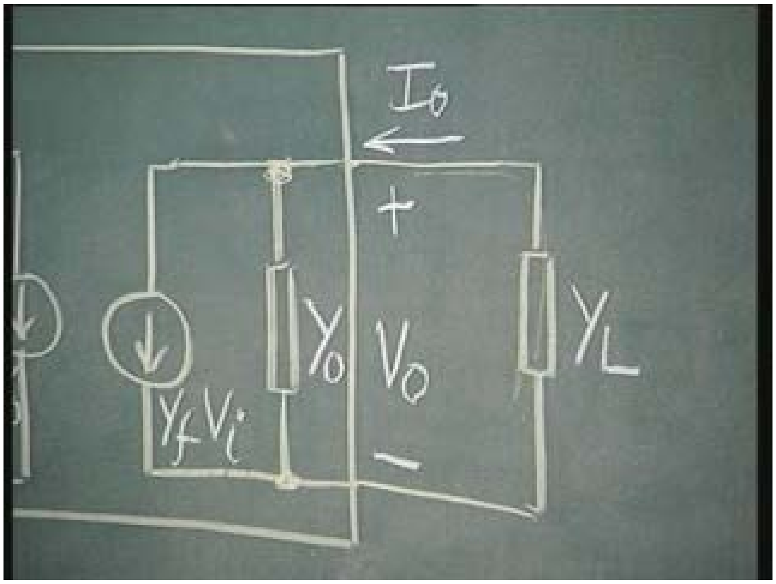

That is what we have derived here. So, this is an important equation for voltage gain V naught over V i.

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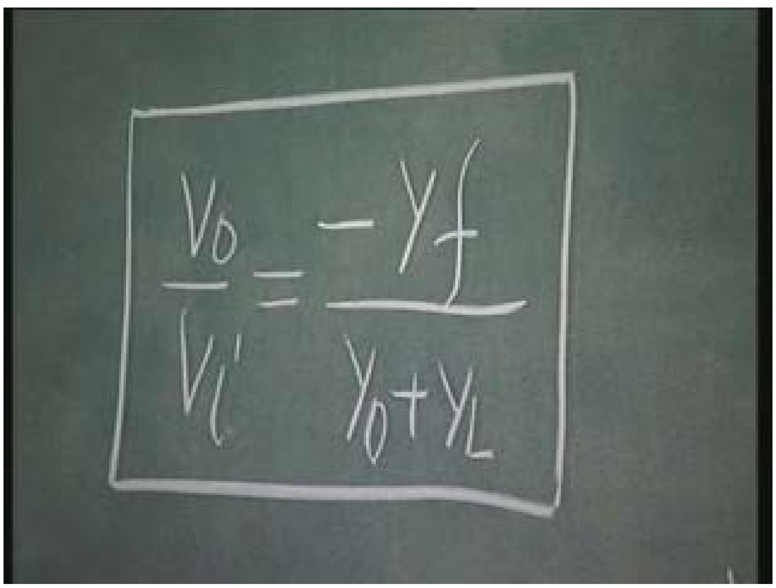

Now, once we know V naught in terms of V i, we can substitute this in the first equation and get I i equals Y i V i minus, Y r into Y f divided by Y naught plus Y L. This is ... This minus Y f into Y naught by Y L, minus Y f divided by Y naught plus Y L, is the term that we are replacing it with, into V i is V naught. So now, we will get I i by V i which is nothing but input admittance of the amplifier, is equal to Y i minus Y r Y f by Y naught plus Y L.

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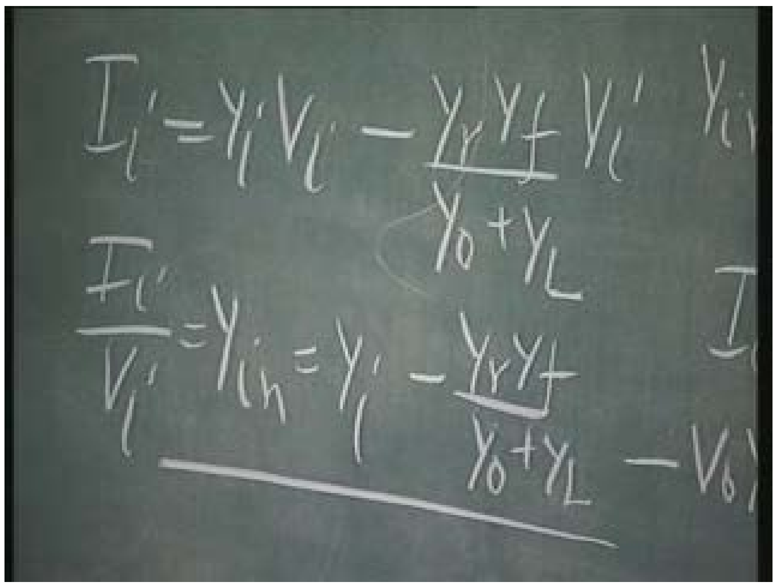

An important relationship, in the sense, that this relationship is valid, whatever be the parameter you select, as long as we replace this parameter with the corresponding parameter. That, what I mean is, if it is Z parameter, then Z in is always equal to Z i minus Z r Z f divided by Z naught plus Z L.

If it is h parameter, h in is equal to, h i minus h r h f by h naught plus h L. If it is g parameter, g in is bound to be equal to g i minus g r g f by g naught plus g L. And therefore, it is immaterial; that is why I introduced the term immittance. Instead of calling this impedance or admittance, it is immaterial what the parameter is. It is called immittance matrix; and a general term that is used is p. So, you can just say that p in is always equal to p i minus p r p f divided by p naught plus p L.

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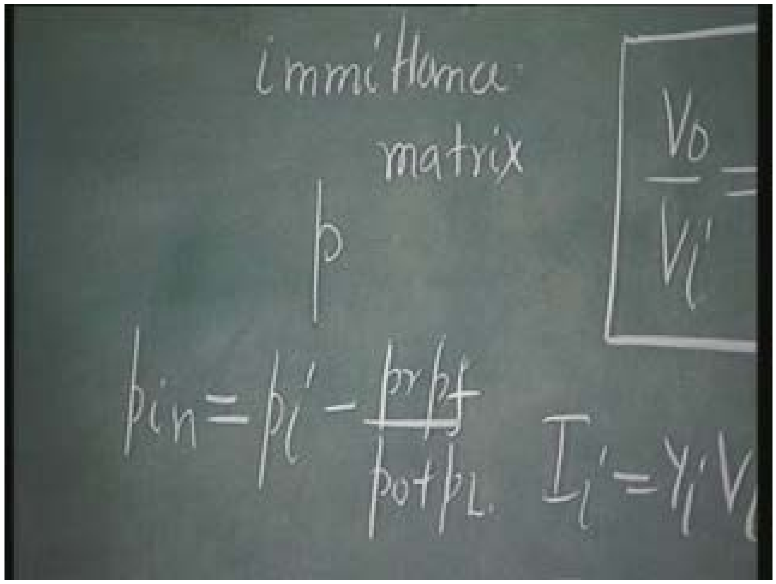

So, now that you know the results in all the other parameters, I would request you to adopt the equivalent circuit approach or equations to derive these relationships and convince for yourself that this is ((.... Refer Slide Time: 08:50)) and it remains unaltered in its nature. So, this is as much about input admittance and voltage gain. This, we had derived in the last class itself by some other approach.

We will now see the other parameters, other important performance factors associated with the amplifier, which is, I naught over I i, current gain. Now, this can be again derived from the equations; but I would like to do it slightly differently, just as we did it in the beginning of the class on amplifiers.

Now that we have evaluated V naught over V i, why not we evaluate I naught over I i, in terms of V naught over V i? That is the best way; because, we have solved already all these equations and therefore we know V naught over V i. So, V naught is going to be equal to, we know again, in terms of I naught, we have got that, is equal to I naught, minus I naught, by Y L.

This is from this equation.

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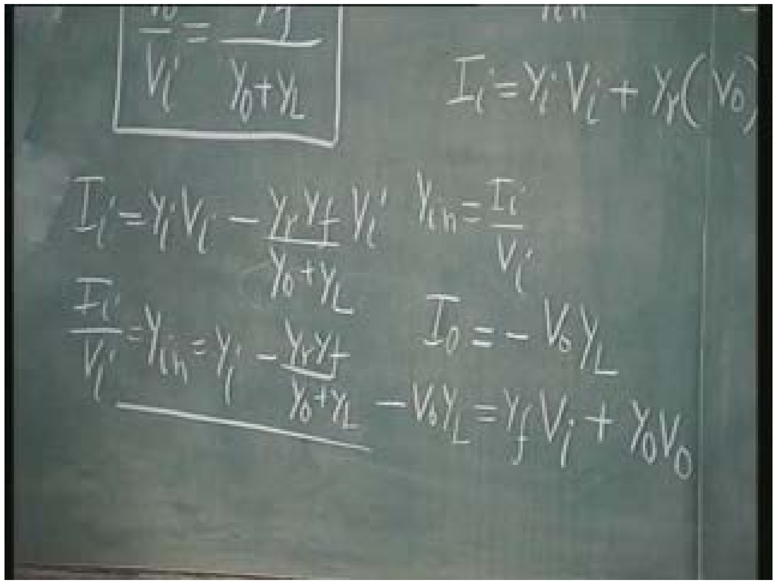

V naught is already known in terms of I naught. Another important parameter, we also know V i in terms of I i. What is it? V i equals I i divided by Y in, from this. You have already evaluated this; V i is equal to I i, this goes there, divided by Y in. Subsequently, therefore, we have V naught over V i is equal to minus I naught over I i into Y in by Y L.

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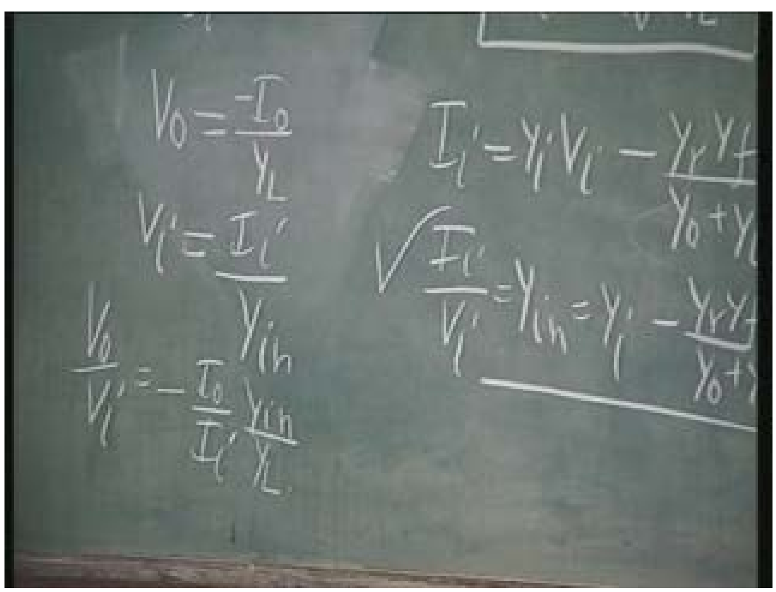

Important relationship, once again. That is, I can either express the voltage gain in terms of current gain into Y in by Y L; or, I naught over I i, therefore, is equal to minus V naught over V i into Y L divided by Y in.

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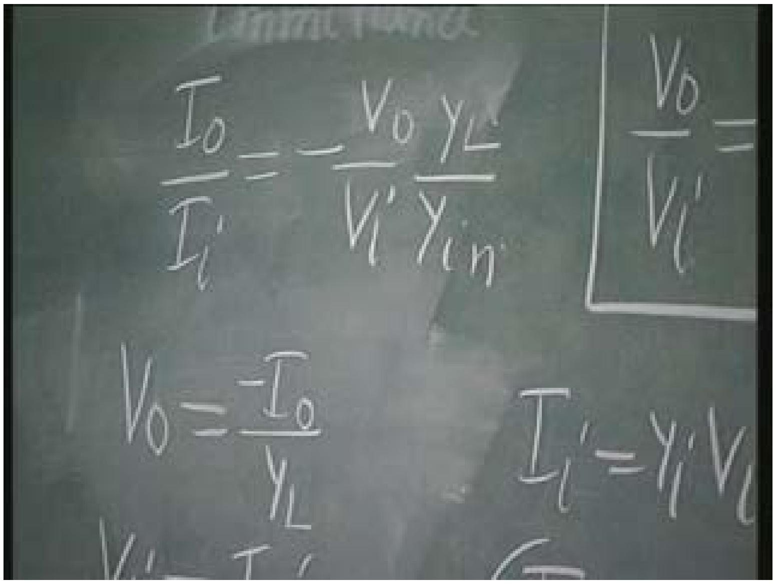

Is that clear? So, this is a simple way of always remembering how to evaluate I naught over I i, given V naught over V i. We do not have to start all over again solving the equation. That can be done independently by solving the equation, eliminating the other variables, V naught and V i from the two equations.

So, this is done knowing the relationship V naught over V i, how to find out I naught over I i. If you know this, then, the power gain becomes a very simple factor. Now, one word of caution. Power, what is power input? Power gain here, in general, is going to be output power divided by input power. This is one way of defining power gain. There are several other ways. This is the most common way of defining power gain.

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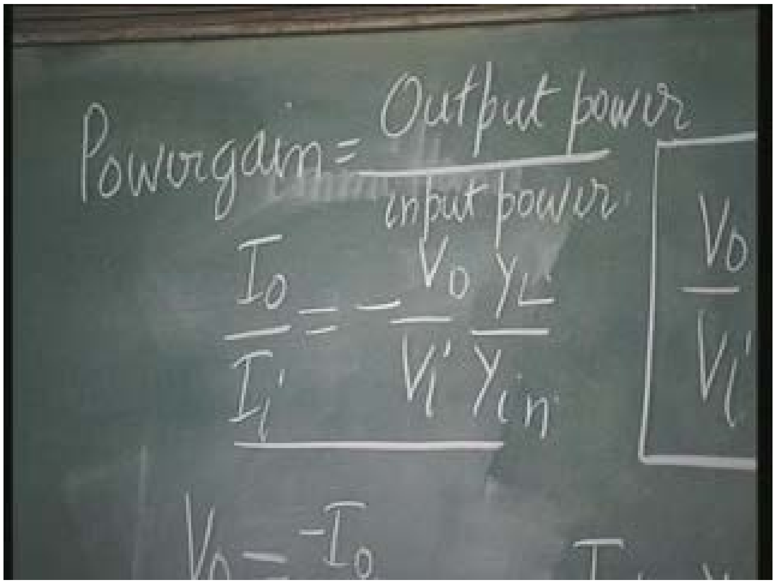

Let us now see how this can be evaluated in general. We have done this already for amplifiers. Let us do it for a two port general network. What is output power? We know that output power is going to be expressed as V naught square, that is the output voltage, rms value, V naught square, divided by R L; or, into, real part of, what? Y L; because, we are talking of admittances now.

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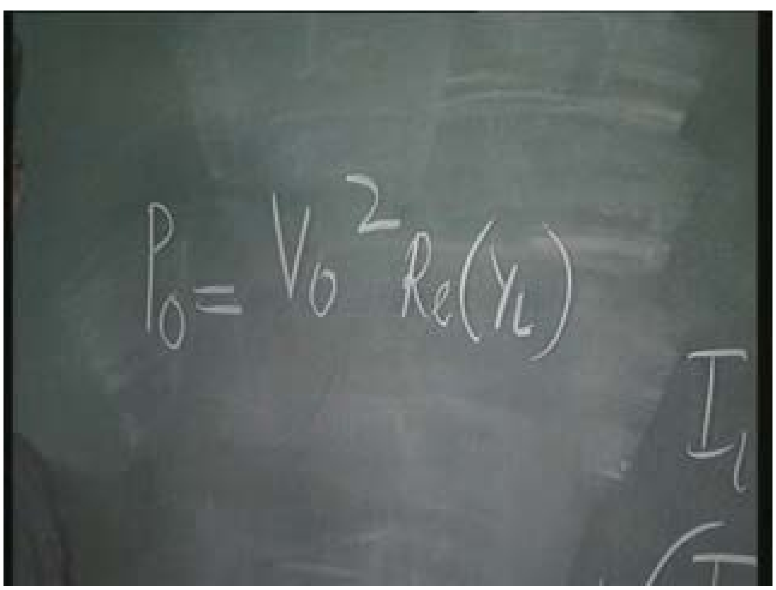

Real part of Y L. This is the input power. This is output power. Input power is, in a similar fashion, what is it? We can now easily see. This is output voltage square into real part of Y L. This should be, input voltage square, real part of what is it? Y in, which is already evaluated. Y in is already evaluated. It is the real part of this that you have to take in order to find out what the actual power that is inputted.

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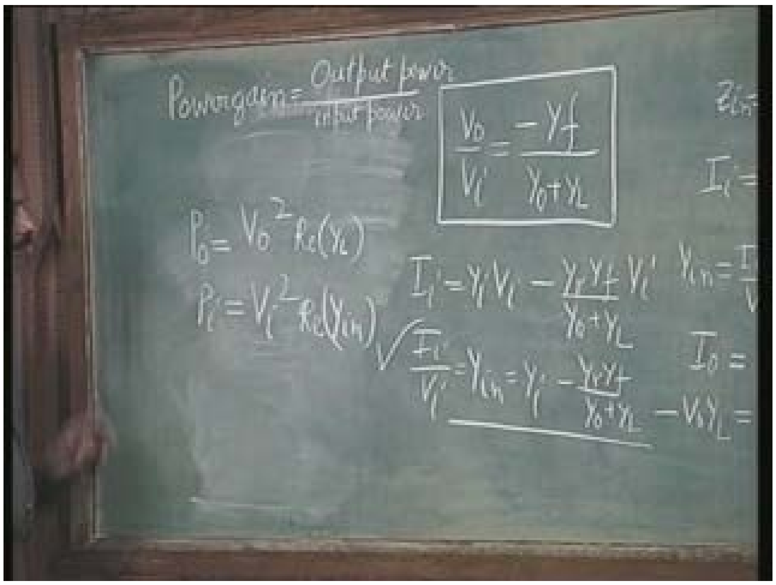

So, power gain therefore is the ratio of these two; that is, voltage gain V naught over V i square, V naught over V i square, into real part of Y L by real part of Y in.

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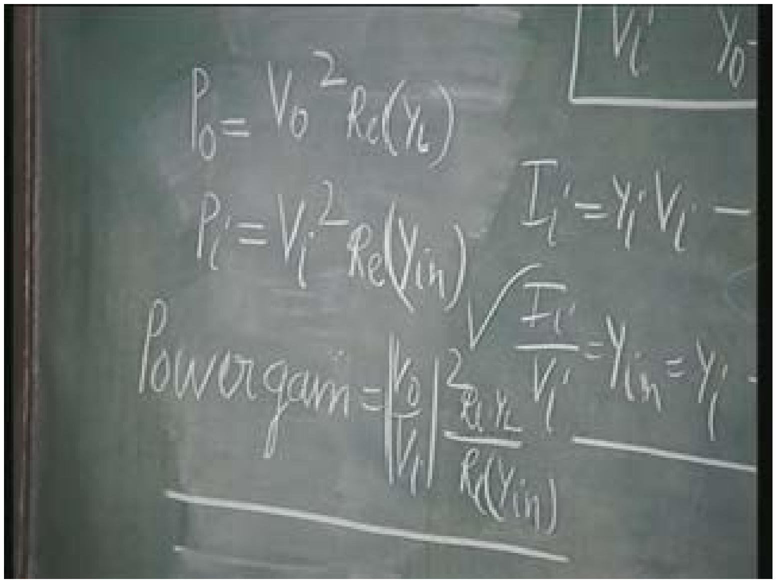

So, the same thing can be derived for any of the parameters, Z, g or h, by adopting the similar procedure and similar definitions. So, in summary, I can say that we have understood how to derive for any two port network. The important performance factors of the amplifier; these are: voltage gain, current gain, power gain and input impedance and output impedance. These are the five important parameters associated with the performance factors.

So, these can be derived in terms of any one of the other three parameters that we have left out; Z, g and h. These are going to be left out as homework problems for you to show that input immittance is going to take the nature exactly similar to this.

Now, output admittance, I have not derived that. We can derive this. Again, I must mention that when I am evaluating output admittance, this is something that has not been understood clearly, I am trying to find out what the output current is. I will remove the load. This is... I will excite it by means of a voltage here, which is V naught. This is not the voltage which has been generated because of input. This is a voltage which I am applying here and finding out what this current is. That is the definition for output impedance.

V naught by I naught, when I am exciting the output. And then, this excitation has to be, this is an independent excitement, this has to be removed. In this case, obviously, if Y f is not existent, then, output impedance is going to be 1 over Y naught straightaway. This is called the self-admittance, Y naught.

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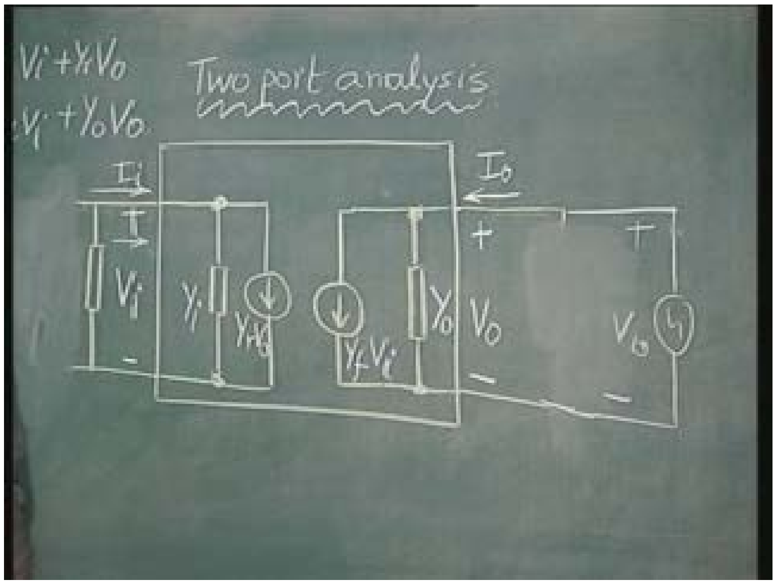

Otherwise, it is going to be determined by this Y f and Y r. Y r is absent; again, the same thing is going to happen. It is not going to be dependent upon what is happening at the... That is, both Y r and Y f, if they are absent, these are responsible for forward and reverse transmission.

If something is applied at the output, this Y r should be present, so that it conveys it to the input and this input is in turn bringing it to the output. So, both Y r and Y f should be present in order to fill something at the output, when I am exciting at the output. If Y r is zero, then nothing happens; nothing happens that is transferred from input to output. So, this impedance is going to remain as the output impedance.

Let us now see what it is. Here, the circuit looks exactly similar to the circuit that is used for evaluating the input admittance. If you notice, V naught is what I am applying here and I have to evaluate I naught. I naught is given by Y naught V naught, this is the second equation, Y naught V naught plus Y f into V i. This V i, I had to replace in terms of what? V naught. Then, I will get the relationship between I naught and V naught.

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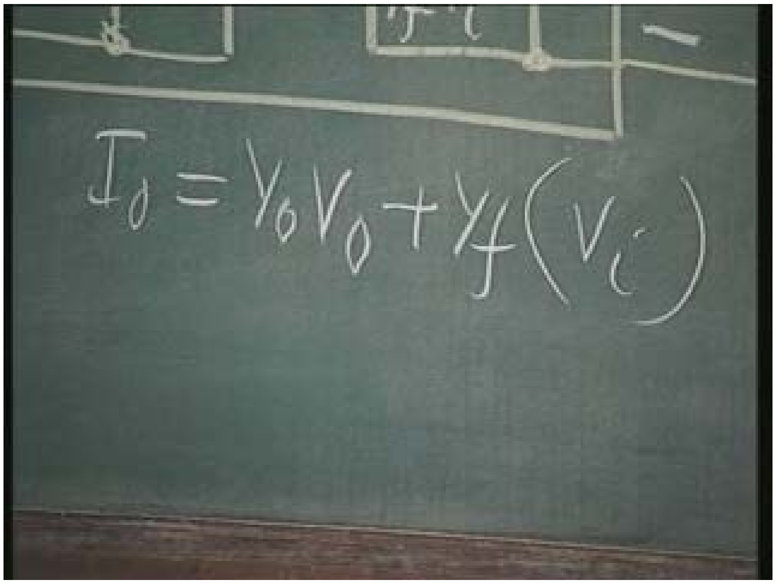

So, because of applying V naught, there is something that is happening here. There is a current that is generated here, which is Y r into V naught. This is the reverse transmission. So, Y r into V naught generates a current here; and because of this, there is going to be current pumped in this, which will generate a V i. And what is that V i is what we have to substitute.

So, V i is generated here because of V naught. So Y r into V naught is the current. And how much is the current that is flowing in this? This current is going to get divided between this admittance and this admittance, so that, that admittance that is going to take up current from this, this is nothing but Y s here, the source admittance. So, what is the current that is going there? That is nothing but Y r divided by Y i plus Y s into... with a negative sign. This is going to be the voltage at this point. This is going to be equal to V i.

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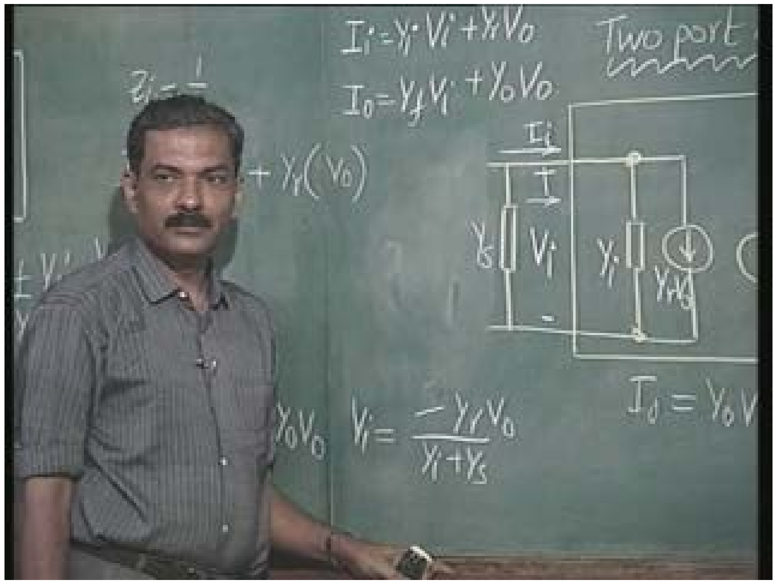

Y r into V naught is the current through this; this current is going to flow through the entire admittance, which is Y i plus Y s; develop a voltage which is V i. Since the current direction is this way, the voltage is going to be plus and minus. That means, there is a negative sign that is to be put; and therefore, this is equal to Y naught V naught minus Y f into Y r by Y i.

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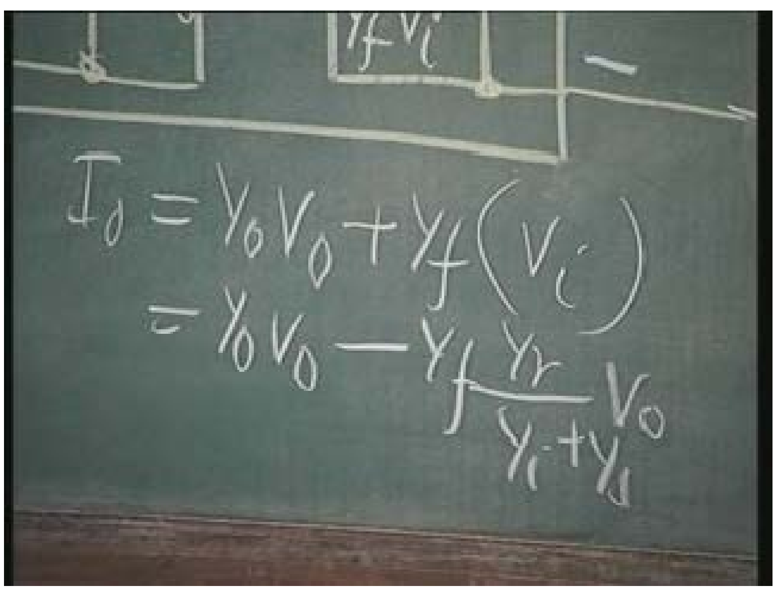

Is this clear? So, I naught by V naught is going to be Y naught minus Y f Y r divided by Y i plus Y s. You can now compare this with what we got for... This is the Y out. This is the Y out.

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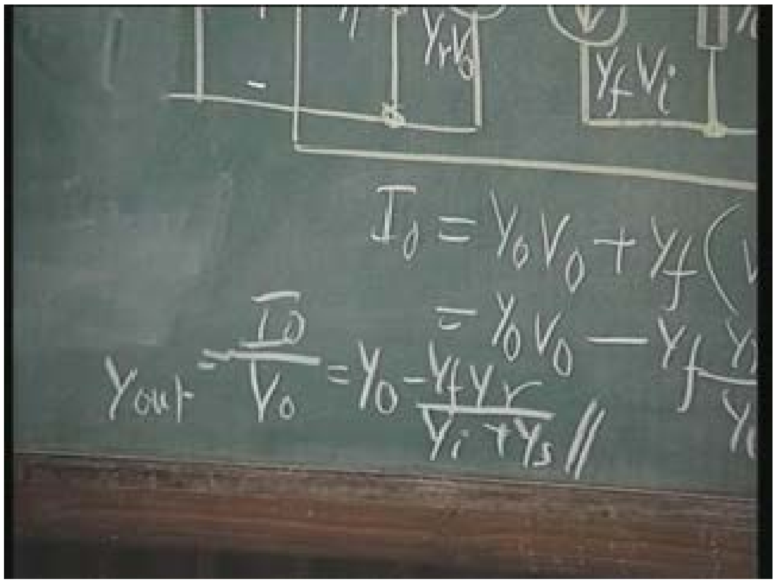

So, compare this with what we got for input Y in, is equal to Y i minus Y r Y f by Y naught plus Y L. Wherever i is there, replace it with o, wherever o is there, replace it with i; wherever L was there, replace it with s; and Y r and Y f also have to be replaced. But, since they come as a product, it is of no consequence; it will always remain as Y r into Y f. So, you can see Y r into Y f product is going to remain unaltered in this change.

So, Y i minus Y r Y f by Y naught plus Y L is the input admittance; Y naught minus Y f by Y r by Y i plus Y s is the output admittance. And in the immittance matrix, p out ... So, this is what we can write. p out is going to be p naught minus p r p f divided by p i plus p s. This is the general output immittance formula.

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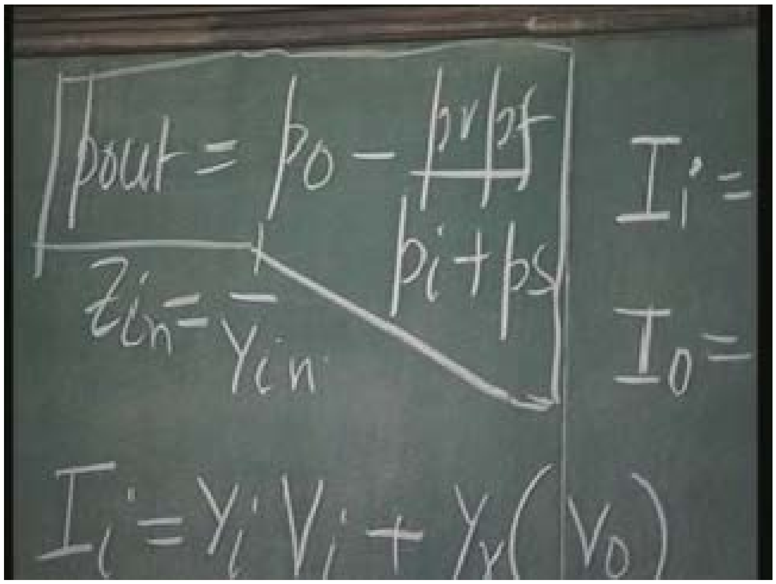

Once again, I request you to show that this is the case in the other three parameters by adopting either equivalent circuit approach or solving the simultaneous equations.

Now, let us take an example here to illustrate what we have learned. For the two port network shown, determine V naught over V i, I naught over I i, p naught over p i, R in; that is, input resistance and output resistance.

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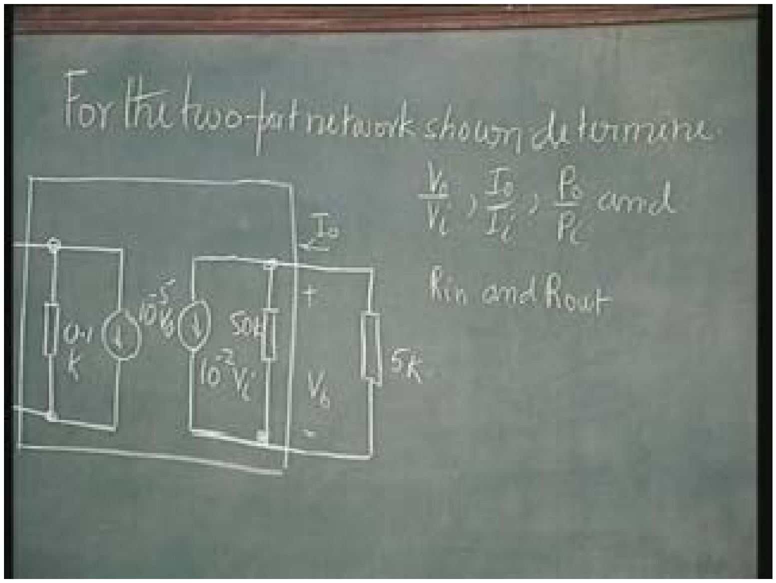

Now, the only difference between what we had earlier worked out in the amplifier case and this; the earlier amplifiers were all unilateral what it meant was that Y r or h r or Z r or g r was zero.

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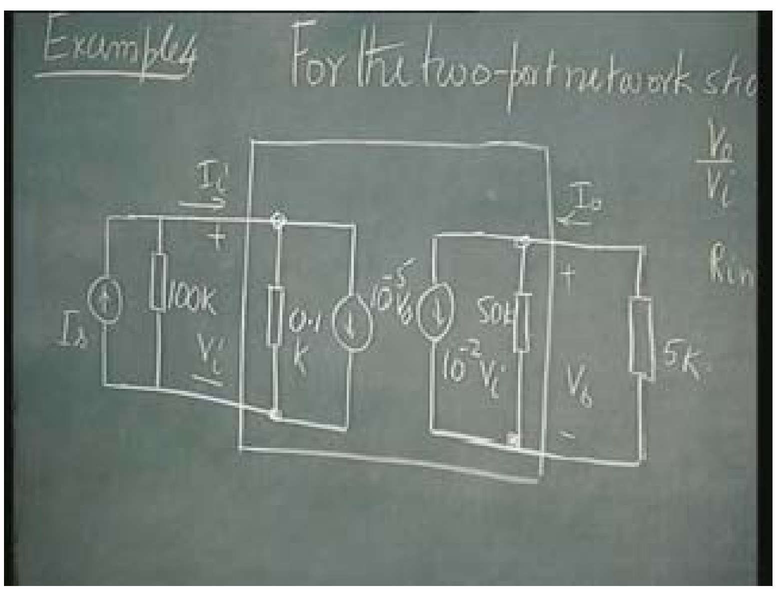

So, transmission was possible only in one direction, forward direction. Whatever was happening here was not getting reflected on to this side. Now, we have put non- idealities everywhere. So, here is the case where we have some reverse transmission. Whatever is happening here is felt here. So, this... what happens here is felt here; what happens here is anyway going to be felt here; that is what we want in amplifier. What is happening here is to be amplified; but what is happening here, should not be reflected here.

So, we do not want any reverse transmission in a good amplifier. But, this is not a good amplifier; there is some reverse transmission here. So, under this situation what happens? Let us consider this. Here, we have a current source feeding on to the input. Whether it can be represented as a current source or otherwise is justified by comparing the impedances. This is 100 K and this is point 1 K; so this is definitely a current source drive. There is no doubt about it.

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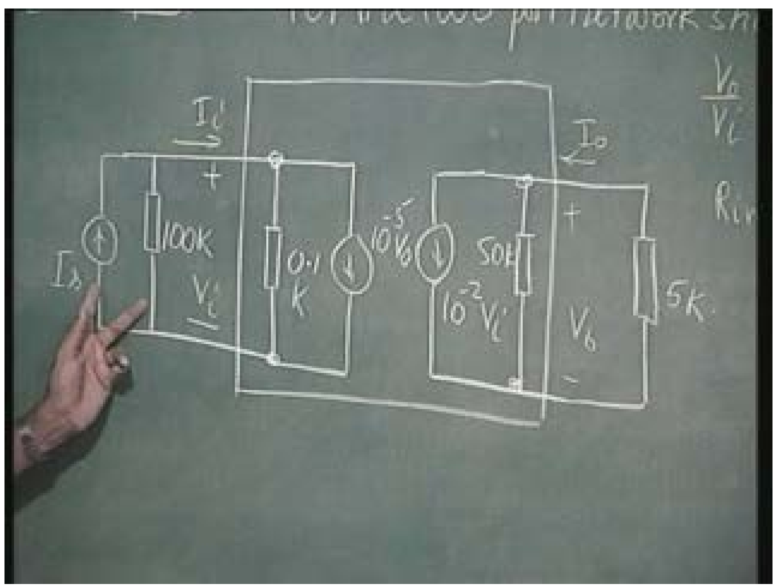

The source impedance is very high compared to what it is here. At this point, the control source, this... whether it is correctly represented as a current source or not can be again justified by comparing it with the load, 5 K. So, 5 K is very small compared to its source impedance of 50 K; so, it is correctly represented as a current source.

Now, if these are the currents due to output and input respectively, then this whole representation can be identified by comparison with what you have learned with Y parameters. So, this is what you should be able to do. That is because, here, I i is equal to V i divided by point 1 K plus this 10 to power minus 5 times V naught. That is the total ((... Refer Slide Time: 26:00)) that is the equation, one equation. The other equation is, I naught is equal to V naught divided by 50 K plus 10 to the power minus 2 into V i. These are the two equations that describe this two port now, which is nothing but Y parameter representation of the equivalent circuit.

So obviously, I have to now put down the Y matrix for this network as... This is the Y matrix. Y i is going to be 1 over point 1 K; Y r, this is Y i; Y r is 10 to power minus 5. You can see that this should be a very small factor in terms of siemens, compared to what? Because, this is now having a dimension of siemens. Compared to other parameters, this parameter, these are all Y parameters; so, this should be very small. Then only, I can call it as a very good amplifier. If it is zero, it is the ideal amplifier.

So now, on this side, Y naught is going to be 1 over 50 Kilo volts; and Y f is the main transmission, 10 to power minus 2 siemens. So all these are siemens. We can see that this should be really a large factor compared to this, in any case, so that it is more unilateral. That means, transmission from here to here is more than reverse transmission. So, these are the factors of it.

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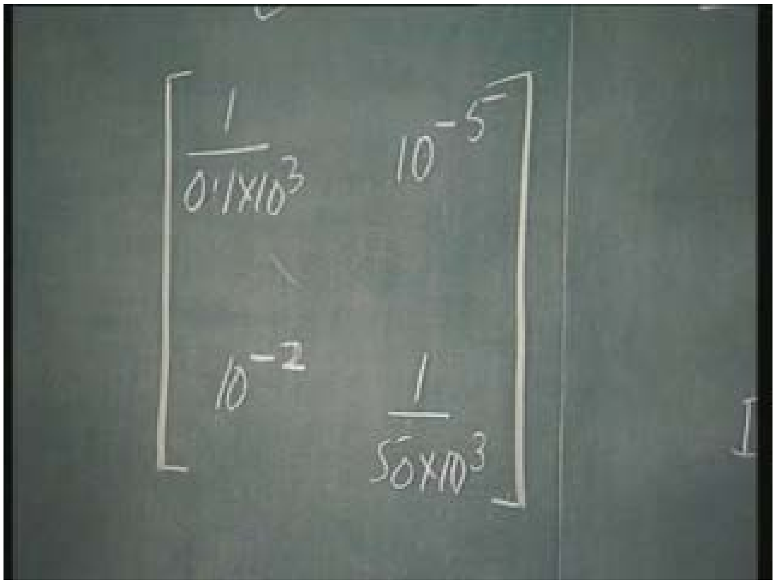

Now, because of these two factors, there is interaction between input port and output port. What happens at the output port is going to be reflected at the input port. So, the input impedance is going to be different from the original impedance of point one K which is the self-impedance. If this is not there, if this is zero, it would have been just point 1 K. Because of this now, it is going to be different form point 1 K. How different it is going to be is what we are going to now see.

Let us first evaluate the voltage gain for this. V naught over V i. This is going to be therefore Y i, this is Y r, this is Y f, this is Y naught.

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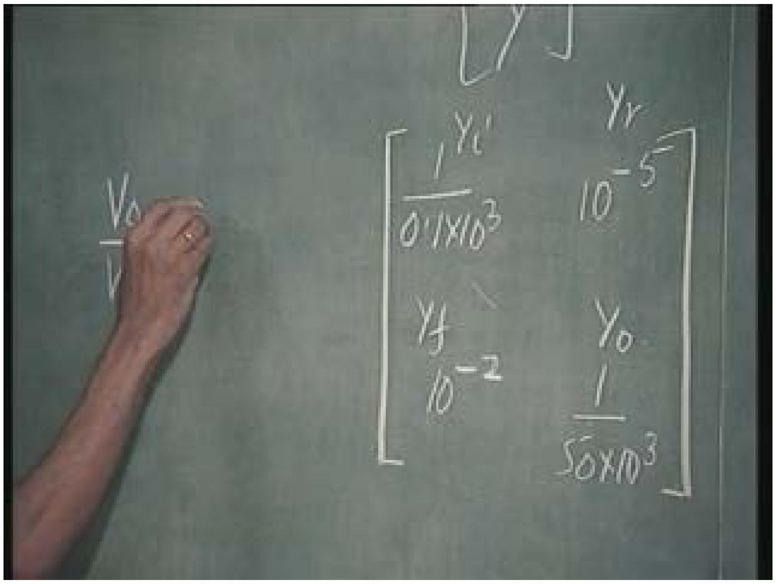

... is going to be minus Y f, divided by Y i plus Y L. So, minus Y f by Y i plus Y L.

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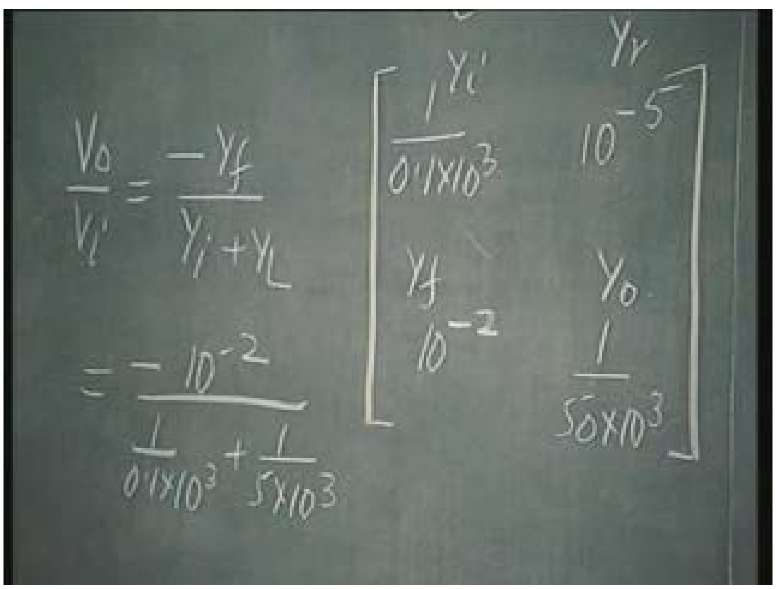

That is the value, which comes out as minus 10 by 10 point 2, sorry, Y naught, this minus Y f by Y naught plus Y L.

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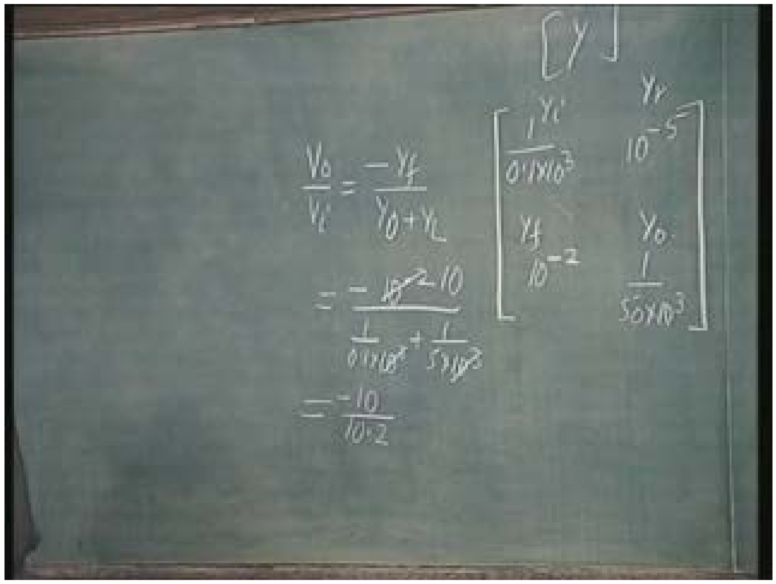

So, which comes out as... This is therefore, 50. So, how much it comes? So, this is 1 by 50 plus 1 by 5; which is, minus 50 by 1 point 1. Minus 45 point 4. So, this is the voltage gain.

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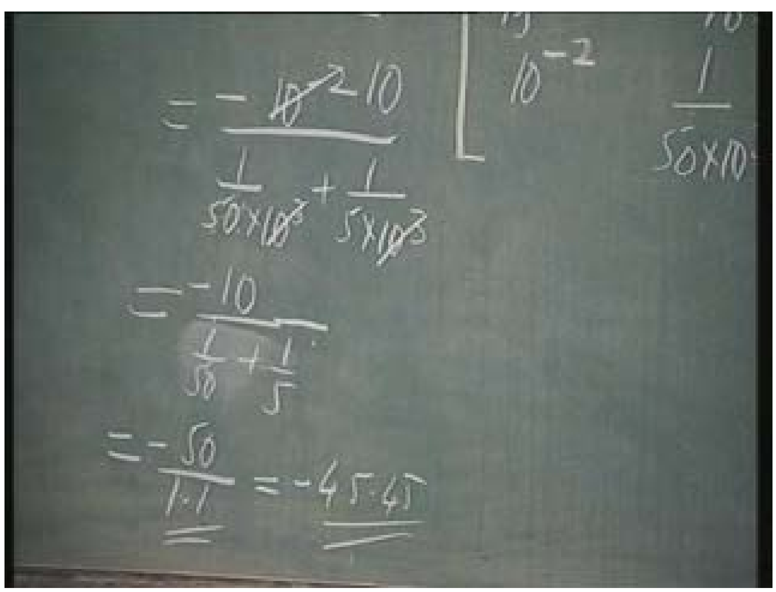

Next, Y in is going to be Y i minus Y r Y f divided by Y naught plus Y L. This factor, we have already evaluated as minus 45 point 45. So, this is Y i. Y i is going to be 1 by point 1 into 10 to power 3, minus Y r Y f, 45 point 45 into, that is Y f by Y naught plus Y L; minus of that is, minus 45 point 45, into Y r, which is 10 to power minus 5.

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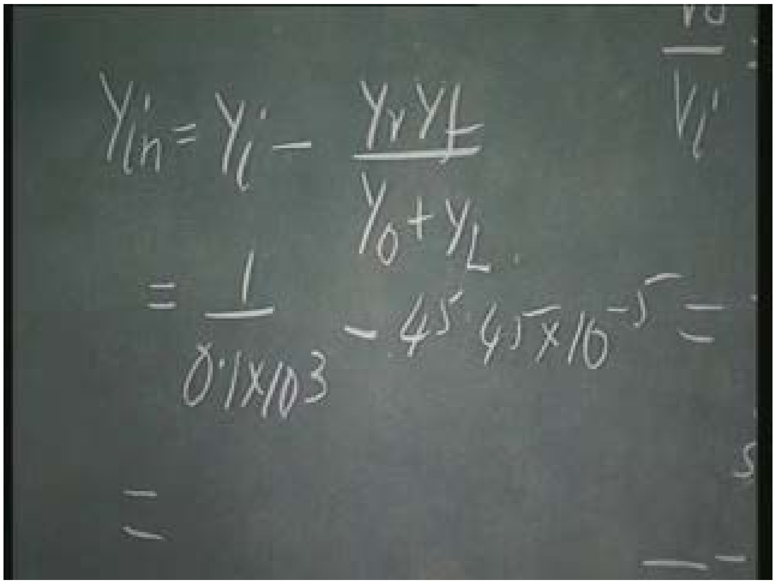

... which is going to be... this is 10 millisiemens or 10 into 10 to power minus 3, minus, point 4545 into 10 to power minus 3. This is going to be... how much is it?

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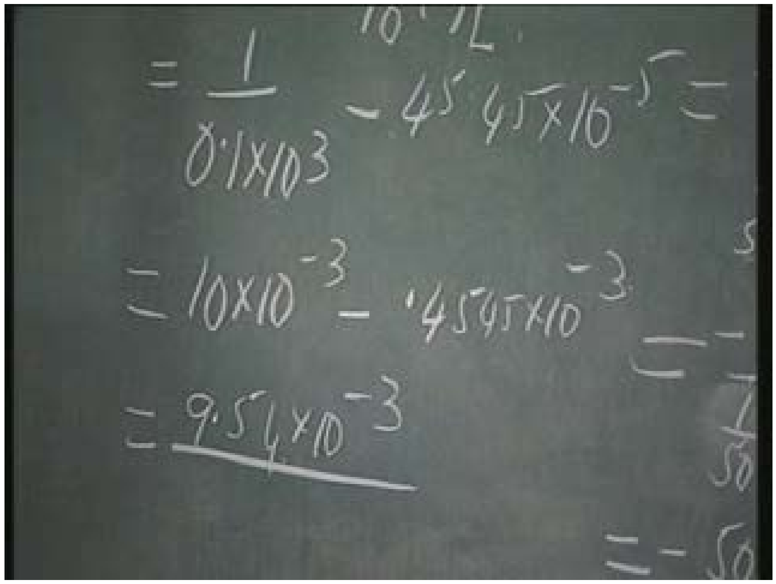

9 point ... which is to mean that R in is equal to 1000 divided by 9 point 54 which is 104 point 8 ohm.

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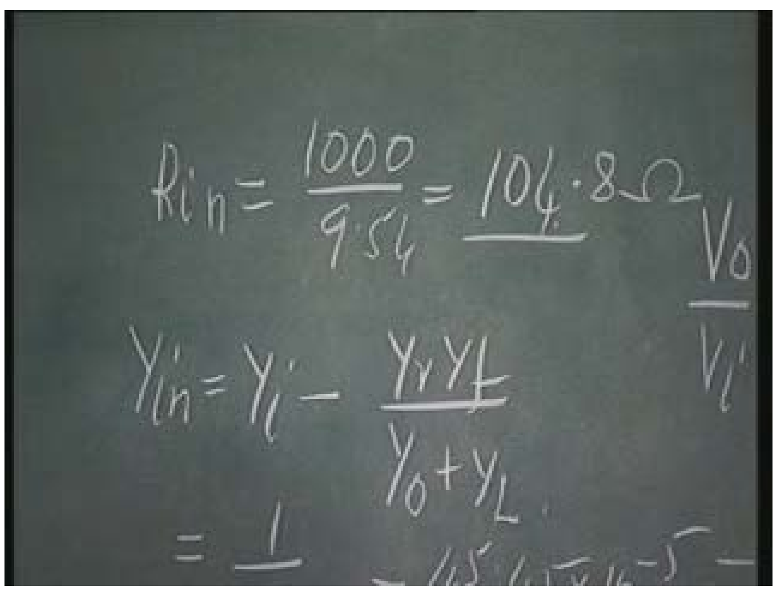

Compare this with what we had earlier. It was 100 ohms; now it has become more than 100 ohms. How did it happen? Because, earlier 100 ohms. Why did it become more than 100 ohms? That is, the effect of the feedback is such that it is now simulating a negative resistance here, such that, the combination of this 100 ohms and what is simulated here is more than 100 ohms.

Because, if it is a positive resistance that it assimilated, it would have become less than 100 ohms. So, the effect of the interaction of the output at the input here is to boost up the impedance from the original impedance of 100 ohms. Original impedance without any feedback would have been just 100 ohms. Because of this reverse transmission, it has become more than 100 ohms. Why did it happen? Because, it is now simulating a negative resistance across this positive resistance and boosting up the input impedance.

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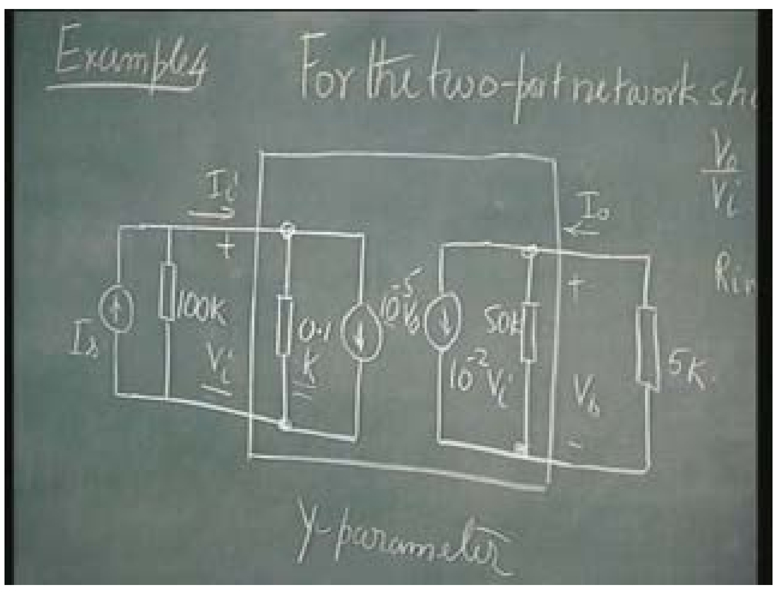

This is called positive feedback. This is called positive feedback. So, why is this impedance more than the self-impedance at the input port? That is because, it is simulating a negative resistance and effective resistance is more than the original impedance.

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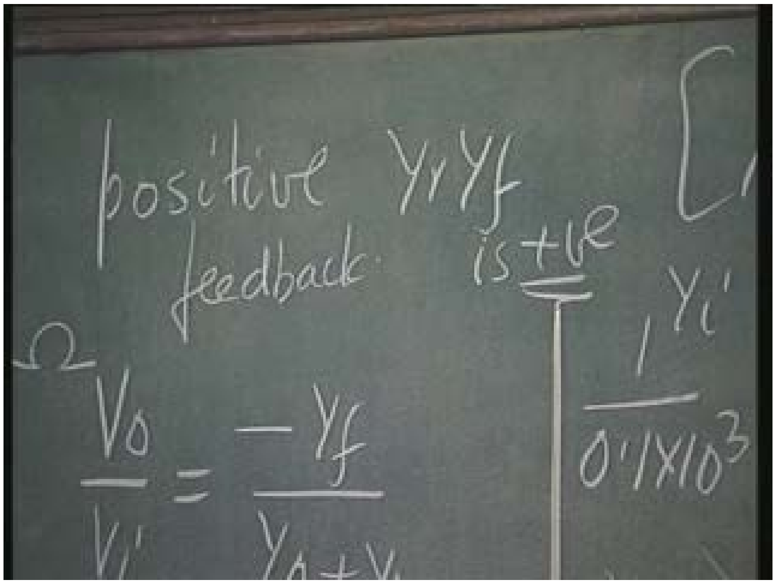

So, this is called positive feedback. How do you recognize that it is a positive feedback? What is the factor that was responsible for this? We know that it is Y r into Y L divided by Y naught plus Y L, which is coming additionally. If this is, assuming that these are positive, this becomes positive feedback only when Y r into Y f is positive. So, we can quickly identify whether it is positive feedback or negative feedback by seeing the product Y r into Y f.

Here, 10 to the power minus 2 into 10 to the power minus 5; that is the factor by which the effect of output is reflected at the input. And, it is getting subtracted from the input admittance. That is, effective admittance becomes lesser or impedance becomes higher.

So, this is the effect of positive feedback. We will discuss more about positive feedback much later; but you should now know that in an amplifier, this, an ideal amplifier, this is not at all wanted. If Y r into Y f is negative, then, it is called negative feedback. That means, negative, what happens at... then? You can look at it.

If this is negative, in this case it is not negative, let us say this is minus or this is minus; if any one of this is minus, then, it can be negative feedback. Then, what happens? This becomes positive; that means, the total admittance increases or impedance decreases. So, this is what happens in negative feedback. In this example, we are giving positive feedback here; and that is why, the impedance is increasing.

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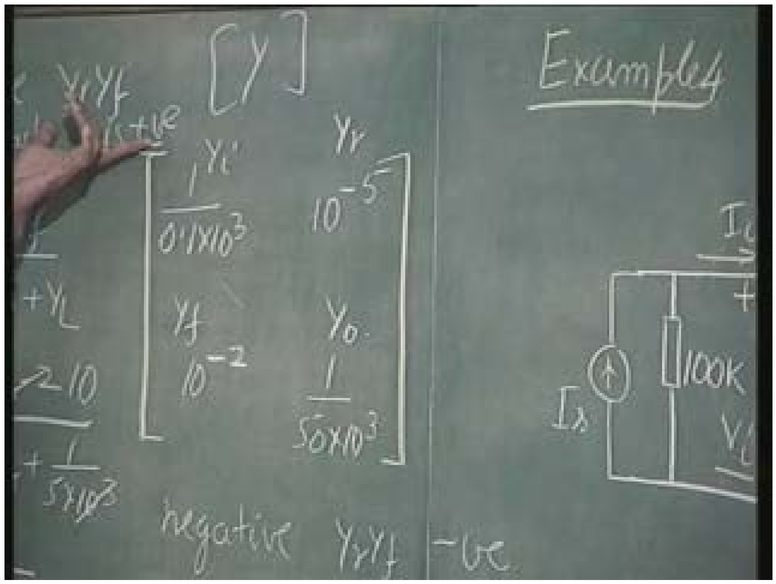

Next, we would like to evaluate I naught over I i. I naught is nothing but V naught, minus V naught by R L.

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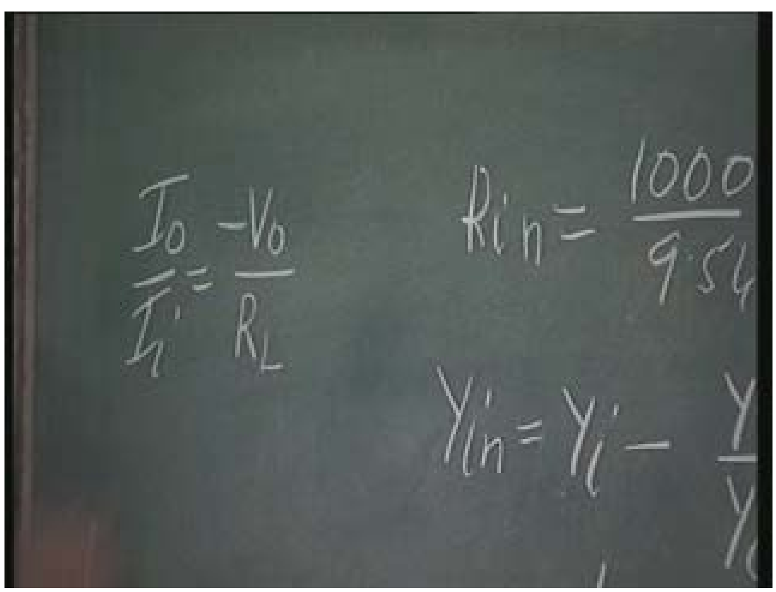

And, I i is nothing but V i divided by R in. That is right. So, if you know the voltage gain, which is V naught over V i, which has already been evaluated as minus 45 point 45, minus, minus, becomes plus; this into R in; R in is also evaluated as 104 point 8; that divided by R L, which is given as 5 into 10 to power 3. This is the current gain.

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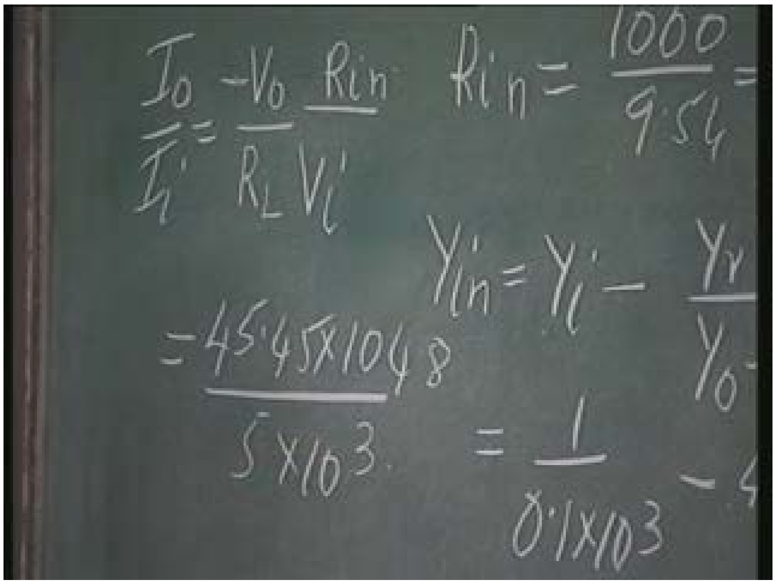

How much is it? Now, this is a good examp... point 9, where the current gain is less than 1; still it is acting as a power amplifier. It is giving you voltage gain and it is having a current gain which is less than 1.

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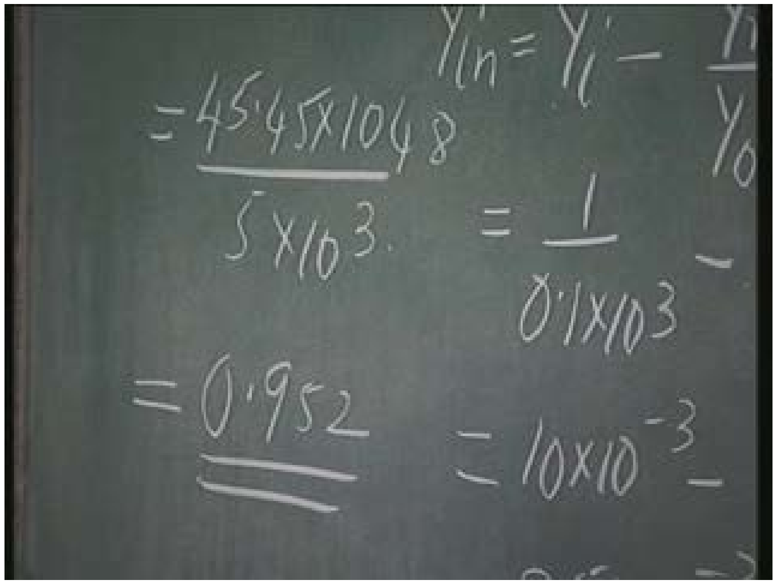

This is quite possible in practical amplifiers; either it has to give a current gain or voltage gain so as to give ultimately power gain, so that it can retain the name of amplifier. So, what is the power gain? This is current gain into voltage gain, magnitude of that; it is 45 point 45 into point 952; which is 43 point 3.

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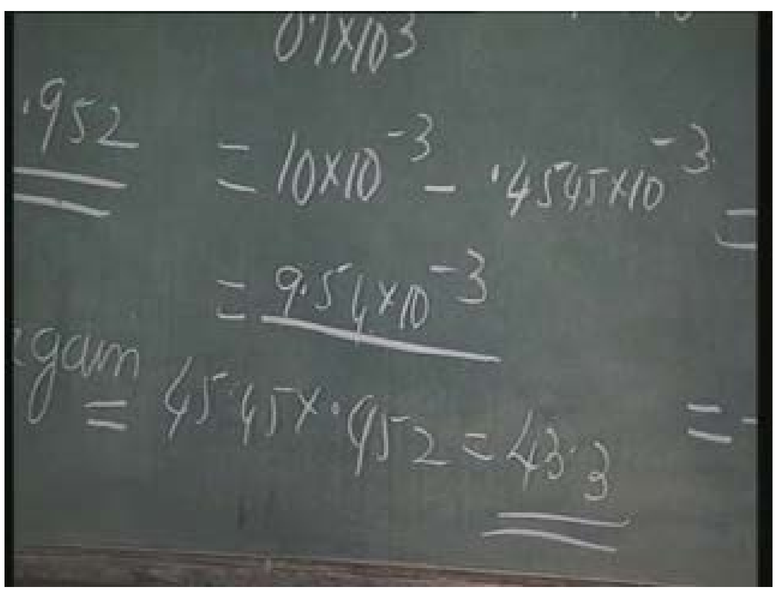

As long as the power gain is greater than 1, it is called an amplifier. This is an active device; if the power gain is less than 1, the two port network can be termed as a passive device, of no use, for amplification purposes. So, power gain has to be greater than 1 in order to treat it as an amplifier. Even though this is giving you less than 1 as current gain, it is ultimately acting as an amplifier because power gain is greater than 1.

Now, we have to evaluate only the final thing, that is R out. So, Y naught Y out is equal to Y naught minus Y r Y f divided by Y i plus Y s. This is what we have evaluated earlier. So, how much is this? Y naught is going to be 1 over 50 Kilo ohms, minus Y r Y f is same as 10 to power minus 7, divided by Y i plus Y s which is 1 by point 1 K plus 1 by 100 K.

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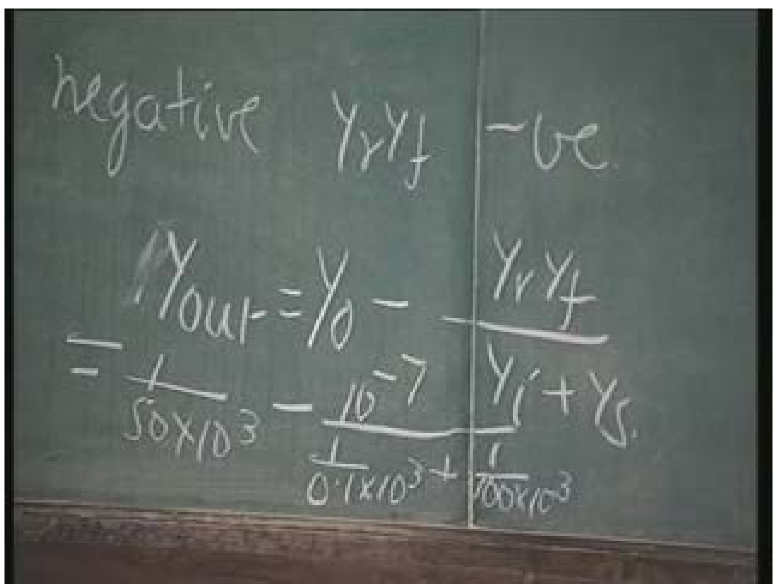

We will write it more clearly up somewhere here. So, Y out is going to be equal to 1 over 50 into 10 to power minus 3 minus; now this 10 to power 3, 10 to power 3 goes, 10 power minus 4; so, 10 to power minus 4 divided by 10 point 01 . So, this is going to be 10 to power minus 3 into 1 point 001. Is it correct? 10 to power minus 4; this is 10 to power... just a minute. 10 to power minus 4 divided by 10 point 01; this is 10 to power minus 5 into 1 point 001.

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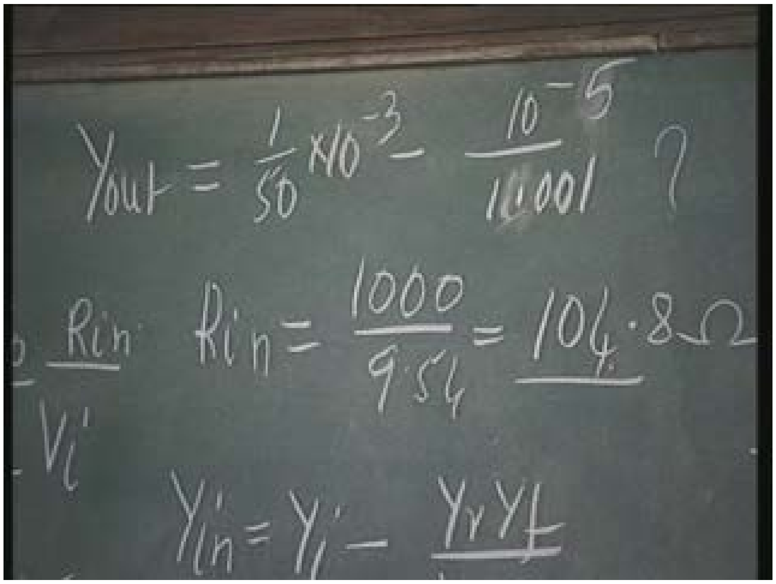

So, how much is this now? This is going to give you 100 by 50 into 10 to power minus 5. That is, 2 into 10 to power minus 5. This is very nearly 1, into 10 to power minus 5. So, this is equal to 10 to power minus 5 siemens, which is therefore going to give you R out, equal to, 100 K.

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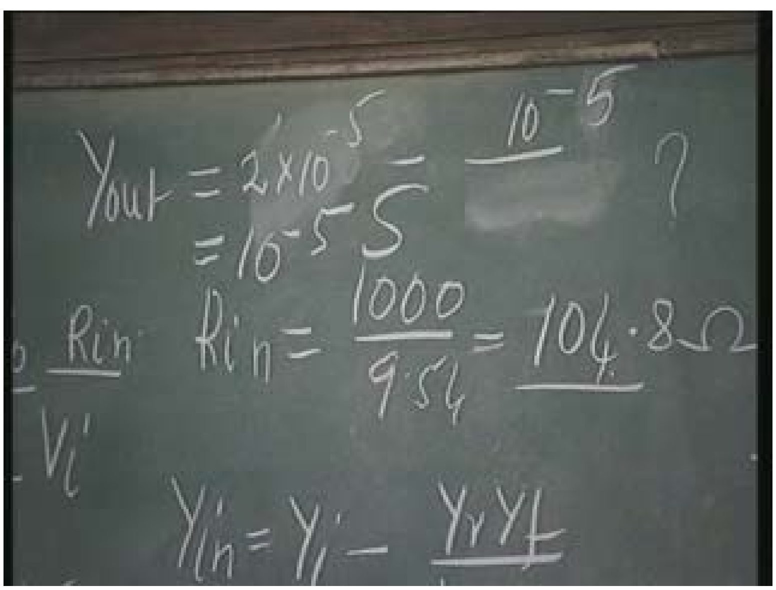

Again, you will notice; a very, the same strange thing that has happened. The self-admittance at the output is 1 over 50 K; or, the output impedance, self-impedance is 50 K. But now, because of interaction from the input, it has become 100 K. It has increased. That means, the same effect is there. Because of positive feedback, the impedance level, both at the input and output, have gone up. From 50 K, it has gone up to 100 K. That means, there has been an effect of negative resistance on this side also. So, this clearly illustrates what happens because of this dangerous negative, that is, reverse transmission factor, which is causing positive or negative feedback.

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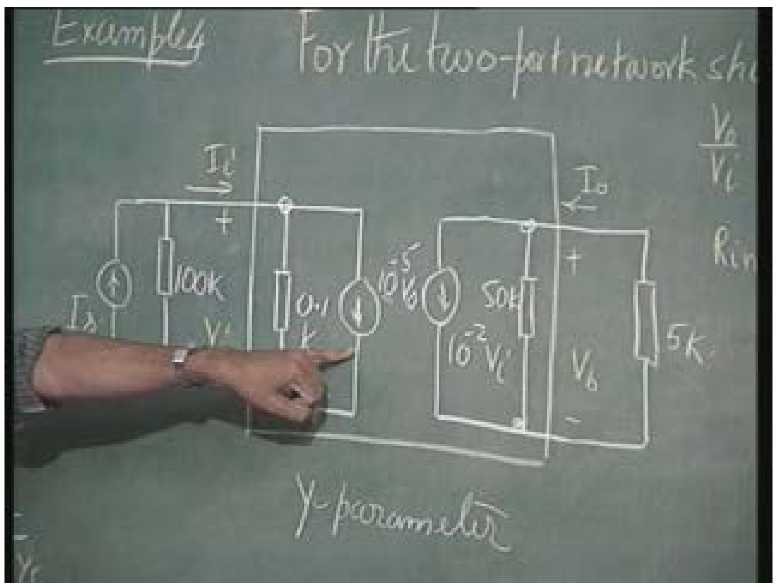

Now, we will, let us see that we can purposely introduce positive or negative feedback, once we understand the amplifier thoroughly. So, before understanding the amplifier thoroughly, we must design amplifiers which have no reverse transmission. This reverse transmission is going to play lot of role in later designs; both in negative feedback amplifiers as well as oscillators. So, we will preserve this knowledge for use at a later date. Henceforth, we will assume that for all our amplifier discussion, until we again raise it, the reverse transmission is zero.

I just wanted to bring this about so as to make it clear to you that this factor is sometimes a troublesome factor in amplifier design. An amplifier has to be unilateral. It has to transmit only from input to output. There should not be any feedback. It is this feedback which causes most of the troubles faced by designers of amplifiers.

So, now that we have discussed two port theory and amplifiers, let us summarize the entire thing. Two port theory as applied to amplifiers, we would like to understand. We said that there are four basic amplifier configurations. They are all called controlled sources.

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Amplifier, therefore according to network theory people, are nothing but controlled sources; and therefore, ideal amplifiers are the following: voltage controlled voltage source, current controlled current source, voltage controlled current source and current controlled voltage source. These are the four types of amplifiers that can be designed.

Now, we saw that these two are more basic than these two because if you have ideal voltage controlled current source and ideal current controlled voltage source, by cascading this with this, we can get voltage controlled voltage source; by cascading this with this, we can get current controlled current source. There is no need for therefore synthesizing these two blocks at all. If you have these two, you can obtain ideal amplifiers of all the four categories. So, these two are more basic than these two.

This is called voltage amplifier, traditional voltage amplifier. This is called current amplifier. This, this is a voltage controlled current source; this is called trans..., it is a current source so, admittance amplifier, or more popularly called, transconductance amplifier. This one is called transimpedance amplifier or more popularly called transresistance amplifier. This is what we have discussed. Then we said, an ideal voltage amplifier has a matrix representation, which is, zero, zero, zero, whatever it is... and has a voltage ratio which is K, something like that. So, obviously, this voltage ratio comes only as basic definition in g matrix. So, g parameter is the only parameter which can represent a voltage amplifier.

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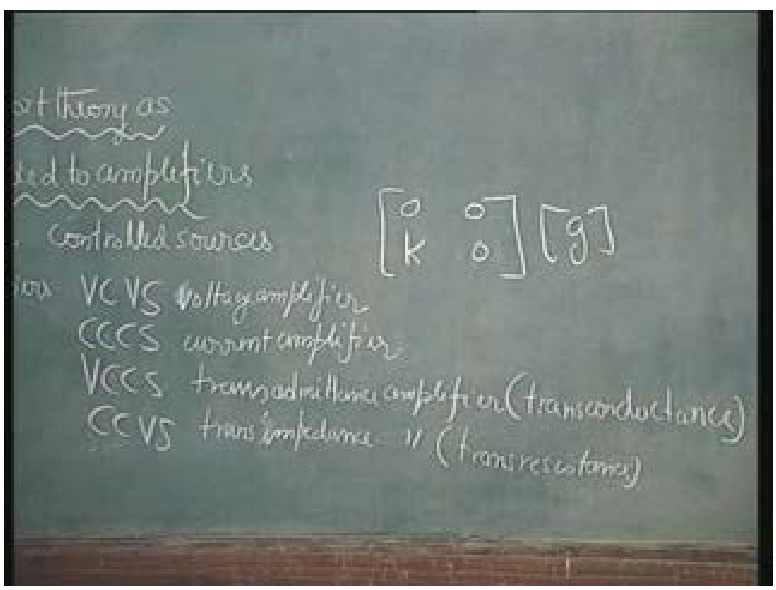

What does it mean? What it simply means is, if I try to represent a current amplifier or a transadmittance amplifier or transimpedance amplifier in terms of g parameters, these will go towards infinity; any one of these three. So, ideal amplifier, these things will become meaningless. Only in g matrix, this can be meaningfully represented. And, these parameters should go to zero; and this is the only ((trans...Refer Slide Time: 48:05)).

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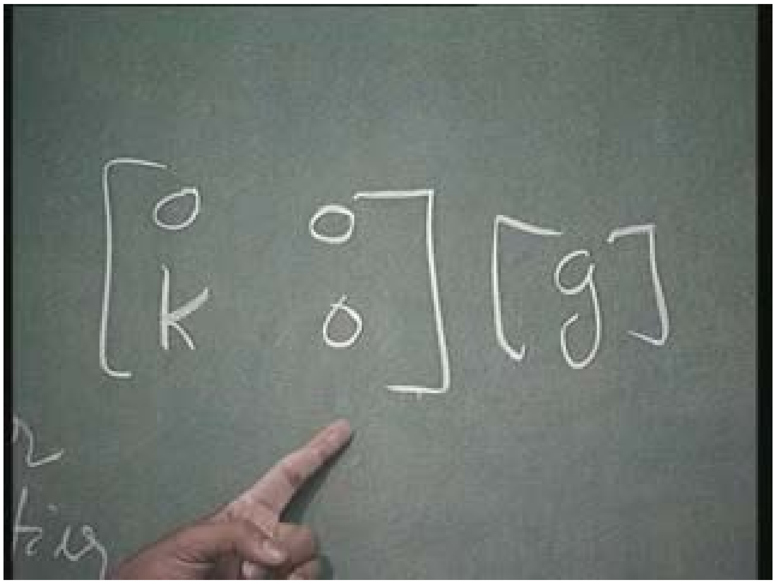

So, that defines a voltage controlled voltage source. If you see this here, this will define g i which is going to zero; that means, the impedance is infinity. This g is going towards zero; this output conductance. So, it is a voltage source. Now, it is unilateral; so, no reverse transmission. So, these things are going towards zero.

Again, this is the representation. Therefore, for current amplifiers, the dual of this; that is, only h parameter, it is the only parameter which is suitable for representation; no other parameter is suitable for...

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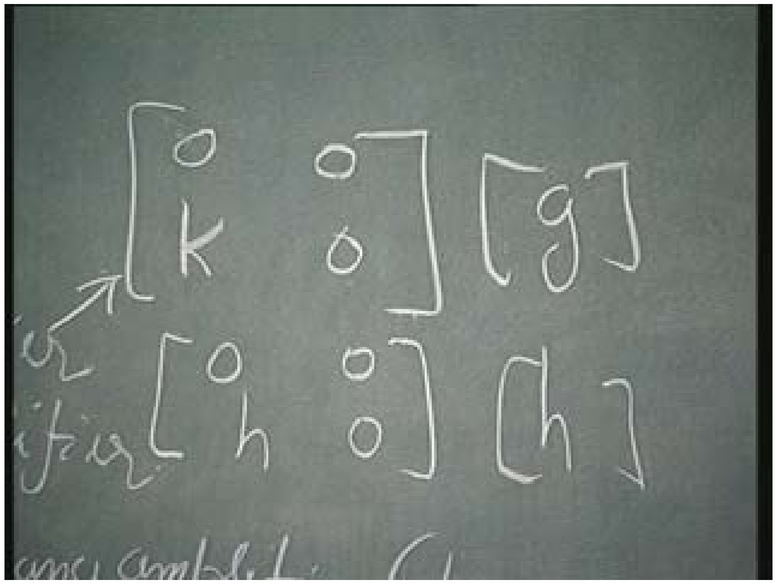

I mean you can represent a non-ideal amplifier by any one of the four; but once you recognize the source impedance and load impedance, you will recognize that particular thing as a particular amplifier. And therefore, you must adopt the proper parameter for analysis; then you would know an idea about the magnitude of these. These will go towards zero and this is the only parameter which is going to be realistically large.

Then, transadmittance amplifier. So, you can see this - voltage controlled current source. Again, this will be zero. The current source magnitude I, is going to be represented as V i into g. So, this is going to be conductance or admittance. So, this is going to be represented by Y.

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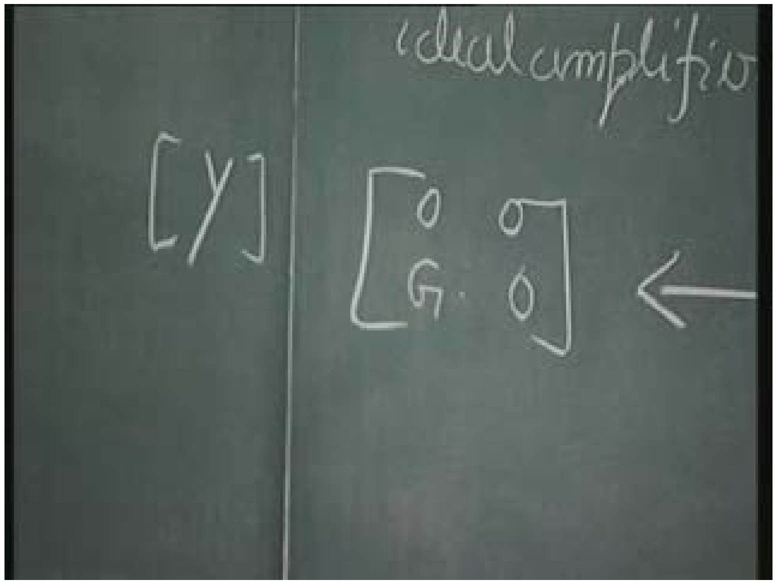

The other one is going to be zero, zero, zero, R; or Z. So this is going to be appropriately represented by Z.

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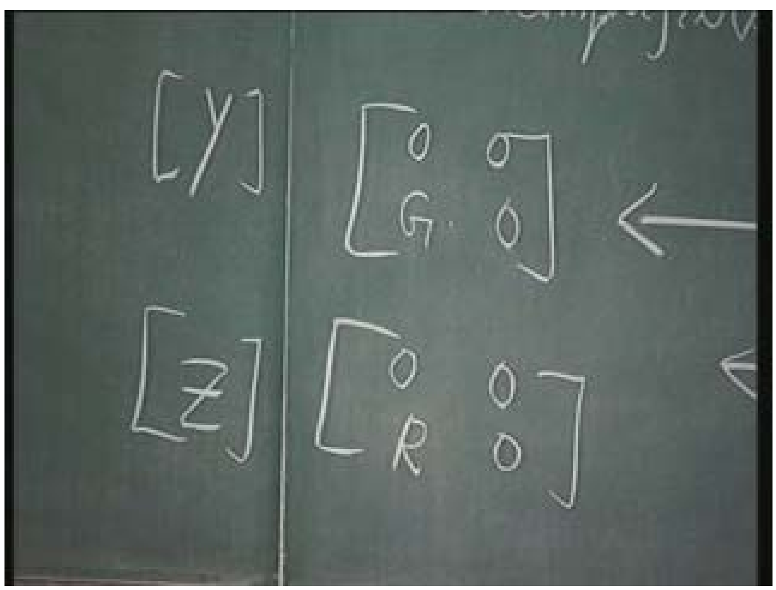

So, this is the summary of what I was trying to impress upon you by trying to correlate the two port theory with amplifiers. This, you must remember as the basic theory necessary for you to understand the concept of amplification itself; and these factors being zero, indicate the amplifier to be unilateral.

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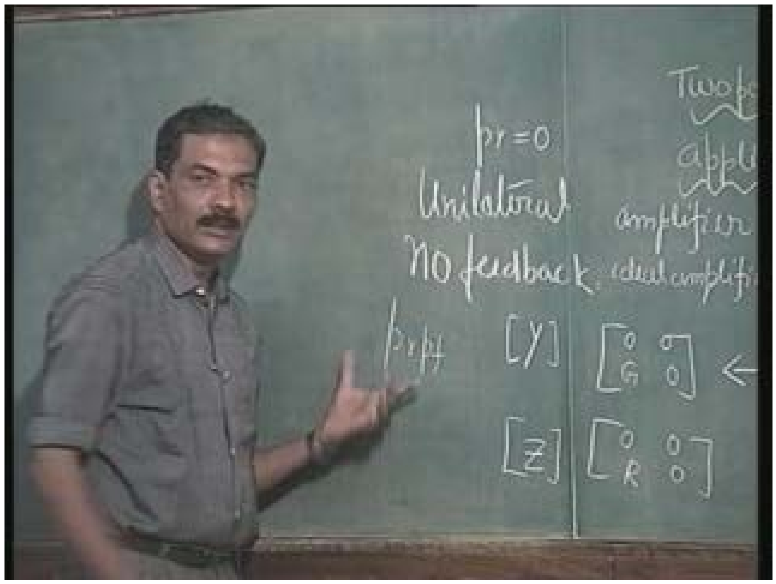

That means no what? feedback. So, this, let us say, p r being zero in any one of the four indicate the unilateral nature of the amplifier where no feedback is there. And p r into p f, the sign of this, indicates whether it is positive feedback if it is positive; negative will indicate that it is negative feedback. More about this feedback, we will learn later.