Introduction to Electronic Circuits.
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Lecture-8.
Operation Amplifiers and Diodes.

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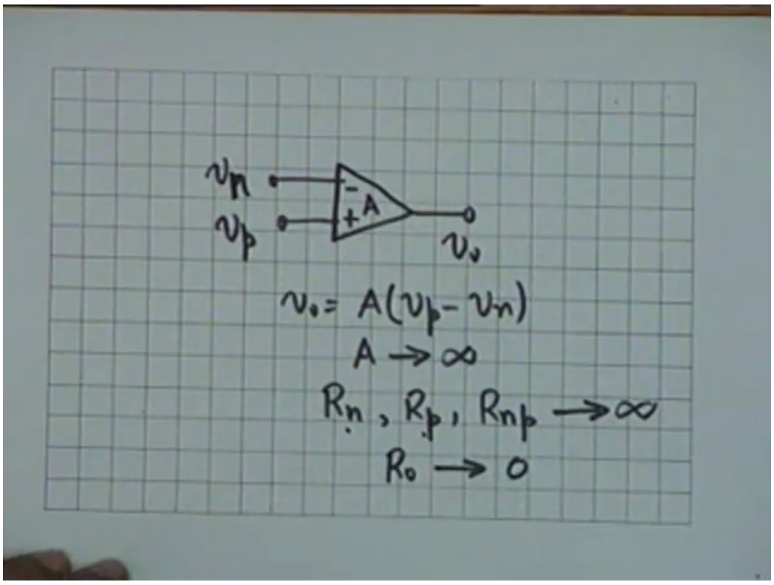

Professor: Discussion of operational amplifiers and in addition we shall consider diodes. As you recall on the last occasion we had introduced the model of an operational amplifier as having 2 inputs and one output, the 2 inputs are marked with negative and positive signs, the gain is capital a is written inside the triangle, the 1st is the inverting input, the 2nd is the noninverting input and this is the output and the model of the op-amp is that if the 2 inputs are vn and vp and the output is v0, then v0 is equal to capital a vp - vn where capital a ideally dense to infinity, rn, rp and rnp respectively denote the input resistance looking into the noninverting.

I am sorry, the input resistance looking into the inverting terminal, input resistance looking into the noninverting terminal rp and the input resistance looking between the inverting and the noninverting terminals rnp, all of them tend to infinity. Input resistance is infinite, so that the op-amp do not take any current at their input and the output resistance tends to 0, this is the, this is the situation for an ideal op-amp.

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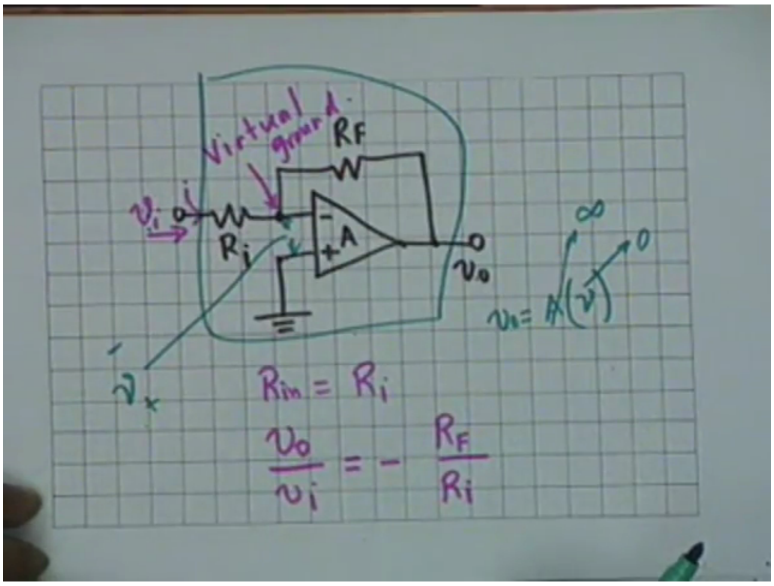

And with this destination and assumptions about an ideal op-amp, we analyse a simple amplifying circuit, in which the inverting, noninverting terminal is grounded and input is applied to the inverting terminal through a resistance let us say r i and there is feedback, that is there is a connection between input and output through another resistance rf and this output is v0. We argued that if the op-amp is ideal, that is if capital a tends to infinity, that the potential difference between this point and this point should be approximately 0. And therefore this point, although not connect to ground behaves like a ground and therefore this point is known as the virtual ground.

Now if this is a virtual ground then obviously the input impedance r in, input resistance looking from here, which is the ratio of the voltage applied here to the current that goes in is obviously equal to ri. The input resistance as face via source connected here shall be equal to this and v0 by vi, let us call this vi, v0 by vi which is the gain of this configuration, we showed that this is equal to - rf divided by ri. Alright, it is simply determined by 2 resistances. If you want, this gain is obviously an inverting gain because the polarity is negative, that is if vi is plus 1 millivolt, then v0 will be -1 millivolts multiplied by the gain factor rf by ri, all right.

Student: That means in this case the relation v0 is equal to a vp - vm does not hold?

Professor: It does.

Student: Then if it does then a must be equal to - rf upon ri.

Professor: The relationship is this, the potential between these 2 points, let us call this as some value let us say v, then v0 is given by a times, if the polarity is like this, a times nu, all right. Since we have assumed capital a tends to infinity, nu tends to 0, this was your assumptions. Now the gain that you are now talking of is not what is applied at the inverting terminal or noninverting terminal directly. It is applied through a resistance and therefore the total amplifier circuit is this. It is v0 divided by this vi, not what voltage appears here, agreed.

The definition of an op-amp remains the same, it is a times the voltage applied to the inverting, noninverting terminal - the voltage applied to the inverting terminal and because of our assumption of ideal op-amp, the input voltage between the inverting and the noninverting terminal is equal to 0. All right. Does that make clear? If you want a noninverting gain, if you want a noninverting gain, then as you can guess, our input shall be applied to the noninverting terminal.

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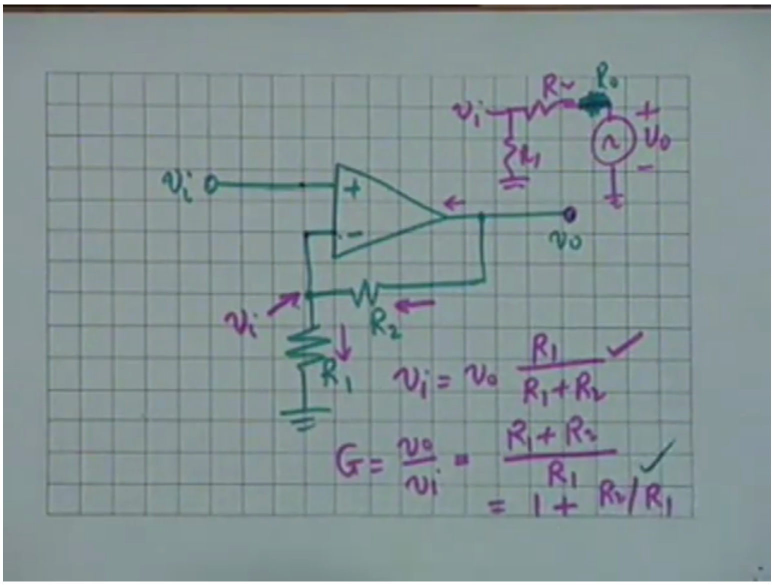

Let us draw it up to show this carefully, to show this clearly. Suppose there is a voltage vi here, what we want is a noninverting gain. In other words we want a v0, we want a v0 which is equal to a positive quantity multiplied by vi, then the configuration is that from the inverting terminal you provide a path to ground through a resistance let us say r1 and the path to the output through resistance let us say r2. This circuit as we shall so, as we shall as we shall show in a minute acts as a noninverting gain amplifier.

Now the analysis of the circuit becomes extremely simple if you take account of the fact that the potential difference between this point and this point should be approximately 0. And therefore the potential of this point should be equal to, should be equal to? Vi because the drop here is 0, this potential should be vi and therefore as far as v0 and vi are concerned, there are simply a potential division between r2 and r1. In other words vi should be equal to v0 times r1 divided by r1 plus r2. Agreed?

You see how simple the analysis is and therefore the gain g which is equal to v0 divided by vi, v0 divided by vi is equal to r1 plus r2 divided by r1 which is equal to1 plus r2 by r1, the gain is greater than 1, all right. Notice, notice that the sign of the gain is plus, positive, as expected because the input is applied to the noninverting terminal and therefore it does not invert.

Student: So how do we get vi is v0 times r1 (())(9:30).

Professor: Look at this path, look at this path, the output impedance, output impedance of the amplifier is ideally 0 and therefore this point acts as a voltage source. The equivalence circuit would be there is a v0 here, plus - this goes to ground and this comes to r2 and r1, and this is vi, all right. That is how we wrote this relationship. However there is implicit, in this relationship another important assumption that the op-amp at the non-, at the inverting terminal does not take a current, is in that right. Suppose there was a current here, then this relation would not have been valid.

This relation assumes that whatever current comes here flows like this, right. If there is a current here, then the relation would not have been valid. Then your kcl would require that this current should be equal to this current plus the current going through there, all right. So this relationship is valid if the op-amp is assumed to be ideal. The idealness is reflected in 3 things, one is that as far as the output of the op-amp is concerned, it can be considered as a voltage source, as an ideal voltage source. Suppose it was nonideal, then obviously you should have included here the r 0, right and then relationship would not have been valid.

So it assumes that the op-amp is ideal, that the output resistance is 0, it assumes that the input resistance is also, is infinity, that is the input resistance is infinity, that is the op-amp does not take any current at the inverting terminal. What is the 3rd assumption? 3rd assumption is this capital a goes to infinity, so that this potential cannot be different from this potential. Vi comes here, all these assumptions are involved in this relationship, all right. So in practice it will be slightly different from 1+ r2 by r1. Actually it will be higher or lower? It will be lower than this because the op-amp shall take a current, the output resistance shall not be 0 and capital a shall not be infinity, so the actual voltage gain would be slightly lower.

But this relationship is one of the key relationships. Now you notice that in the inverting, in the inverting amplifier configuration, what was the input resistance faced by the source? It was equal to ri, that is the resistance connected. So it is not infinity, it is finite. On the other hand, in the noninverting configuration, what is the input resistance faced by vi? Infinity, is not that right? So this is an important difference between the 2 connections, noninverting, noninverting and inverting. In the noninverting configuration the input resistance is maintained at infinity, whereas in the inverting configuration the input resistance is determined by an external resistance, that is connected between the source and the non-, the inverting terminal of the op-amp.

Student: (())(13:08).

Professor: Why?

Student: Why do we do?

Professor: Why do we do what?

Student: We connect resistance in this case and not in that?

Professor: We want a noninverting gain, we want a noninverting gain like this in the configuration. If they want and inverting gain, then the previous circuit that you drew, this is the configuration. Why do we do that, you want to get a certain gain and so we determine the gain through 2 external resistance rf and ri. Right.

Student: What will happen inverting consideration if we do not have any external resistance?

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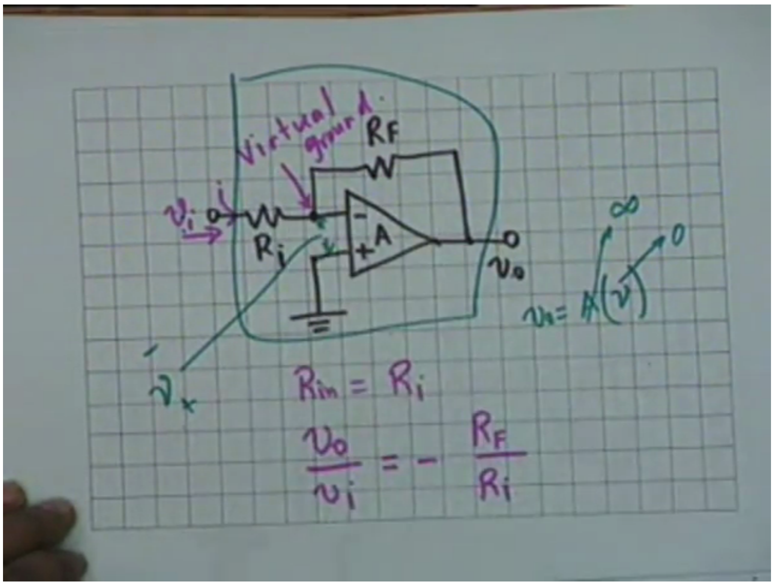

Professor: We do not have ri? Okay, then again shall be infinite. What happens then if ri is not there, vi is applied directly here, all right, directly at the input terminals of the op-amp. Which means derivative multiplied by a, which goes to infinity, your v0 shall go to infinity. But as i said v0 in a practical op-amp cannot go to infinity, it is limited by, it is limited by the power supply. So if the power supply is plus -12 volts, v0 will saturate, it wants to go beyond 12 volts, +12 or -12, all right, so it cannot go, it saturates at either +12 or -12. So if you apply directly let us say 1 millivolts source at the op-amp input terminals, what you will see at the output if you put in a cro, the baseline will go up +12 or go down by -12 and it will stay there, so it saturates. Yes, is there any other question?

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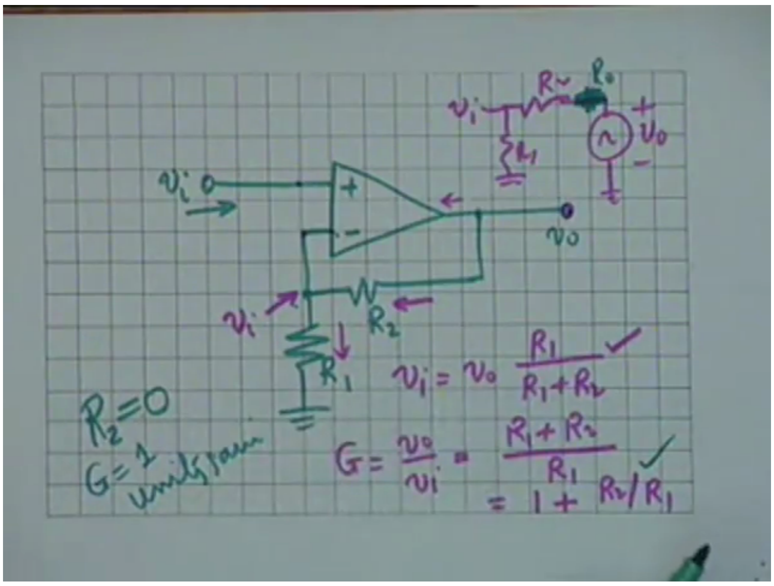

Okay now look at this configuration again and suppose r2 is equal to 0. Suppose r2 is equal to 0, in other words this is directly connected, then the gain becomes +1, is that correct? And therefore it is called a unity gain configuration, unity gain. This deserves a little more, little more closer look, so let us draw it again here. Now if r0 is 0, if r2 is 0, do i have to put an r1? You see the gain is one plus r2 by r1, if r2 is 0, r1 can as well be infinity. Is not that right? And therefore i do not need to put an r1, is that clear? And therefore this is the simplest possible op-amp circuit giving a gain of plus1.

You might ask why should we get a circuit with the gain of plus1. Well it provides isolation, if you apply a voltage source here, okay, then the output and input are isolated because the voltage source does not deliver any current but we are transferring the voltage source here, it is actually a transfer from input to output and the 2 sources then become isolated with respect to each other. The simple equivalent circuit would be this, vi, can v i allowed to have an internal resistance? Can the source be allowed to have an internal resistance, why not?

The op-amp does not take any current, so it could be any internal resistance, any internal resistance, let say rs and at the output you simply get v0, which is equal to vi because the gain is unity, all right. Now you see that if i connect a load here rl, then the current in the load would be vi divided by rl. On the other hand if i had connected it directly here, a current would have been vi divided by rs plus rl. In other words a load would affect the current in the load would depend on rs, all right, which is not the case here because, because vi, whatever the source impedance is, is connected, is transferred directly to the output.

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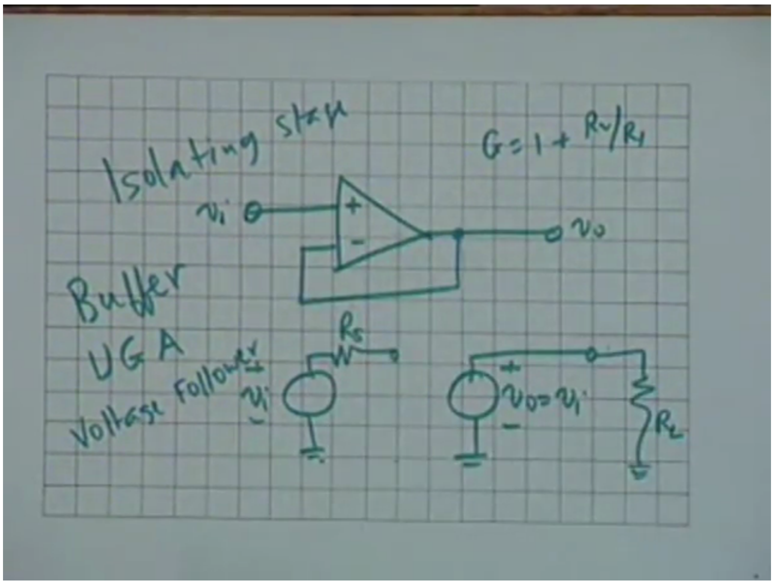

And therefore the load current, load current or the voltage shall remain vi irrespective of what rs is. So it provides an isolation between the input and the output and in that sense it is given various names isolating stage or more popularly it is known as a buffer stage, buffer, between the input and the output the op-amp acts as a buffer. It is also called a unity gain amplifier, uga, unity gain amplifier or it has got various names, it is also called a voltage follower, that is the output voltage follows the input voltage and therefore it is called a voltage follower.

It is a very important circuit to get again of plus1. One more question that one should ask at this stage is, the gain here is one plus r2 by r1, that is it is greater than unity. Once the gain in the inverting configuration was - rf by ri which could be less than one or greater than 1. It could also be equal to -1 if rf and ri were equal. Is the point clear? If rf and ri were equal, the gain would have been -1, is rf is less than ri, the gain would have been less than unity, if rf is less than or ri the gain is greater than unity. Whereas in the inverting, noninverting configuration, it appears that you can only have gain either one or greater than 1.

The question is, is it possible to have gain less than 1. The answer is yes or no. How do you get a gain less than 1? Negative resistance, now, that is a mess, getting a negative resistance, you have to use another 2 or 3 op-amp to get a negative resistance. Can you suggest a very simple procedure. Why do not you, before applying here, why do not you attenuate by the required factor? All right. Suppose if i want a gain of half, then what i do is i make r2 equal to 0, r1 equal to infinity and then i is used a potential divider here, that is it, i can reduce the gain to half but in the process i also lose something, what is it that i lose?

Student: (())(20:45).

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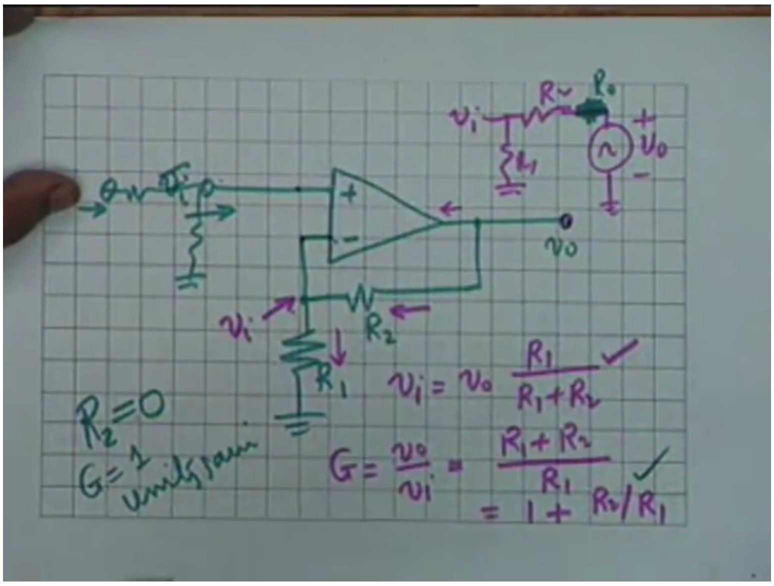

Professor: No, it is not energy. I lose the advantage that the input impedance now no longer becomes infinity. The input impedance will be sum of these 2 resistors, is that understood? The source has to be connected here instead of here. If i want a gain less than 1, then the source has to be connected here. So voltage at the source is the sum of these 2 resistances, op-amp does not take any current, so the infinite input resistance advantage is lost. But it is possible to retain infinite input resistance and also to achieve a gain with this less than 1 in a circuit which shall be experimented upon by you in the laboratory. And that is an interesting circuit, if you cannot understand it, maybe i will explain later on.

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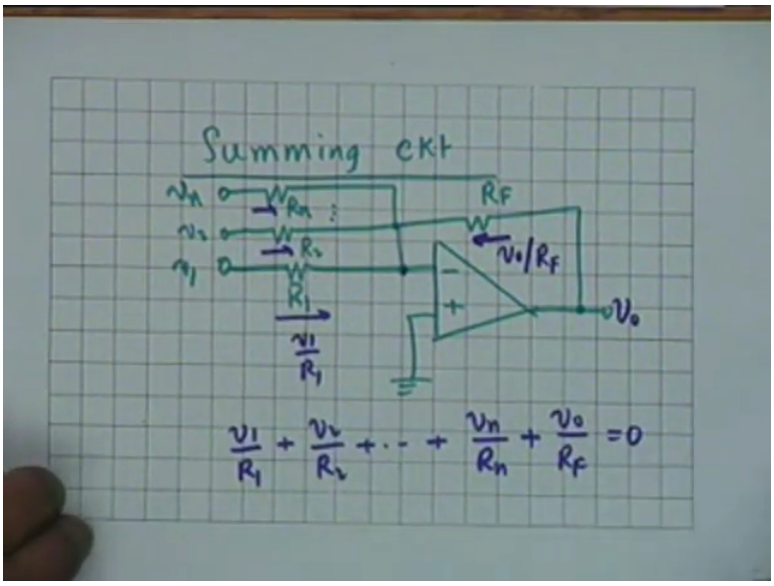

Then we consider another application of an op-amp in summing several voltages, and adding up a number of voltages. And the circuit is very simply this. What we have is the inverting, the noninverting terminal is grounded, we have a number of sources, let us say v1 connected to the inverting terminal through a resistance r1, voltage we do lead saying connected to the same terminal through a resistance r2 and so on up to let say n number of sources vn connected to the same point through a resistance rn. In addition there is a resistance from output to input, let us call this rf, all right.

The number of voltages v1, v2, up to vn, n number of voltages connected to the inverting terminal through a resistance r1, r2, r n and between the output and the input, there is a resistance rf, the feedback resistance. To analyse this circuit, notice again that if this is v0, then the current through this would be equal to v0 divided by rf because this point is virtual ground, alright. So this current shall be v0 divided by rf. Similarly you can find the current through each of these resistors. Because this is virtual ground, the current here will be v1 by r1, the current here will be v2 by r2, the current here will be vn by rn, all right.

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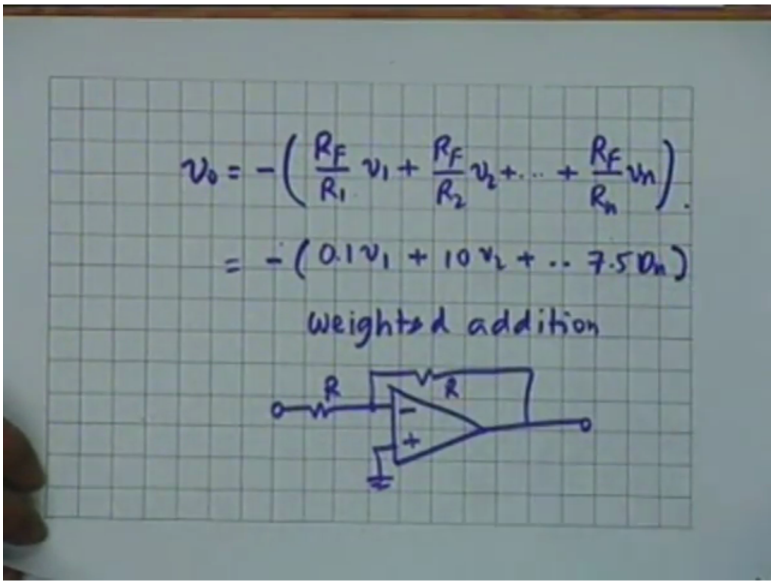

And therefore what you get is by kcl v1 by r1 plus v2 by r2 plus etc. Plus vn divided by rn plus v0 divided by rf, this should be equal to 0 by kcl. And therefore you can find out the value of v0, the output voltage. And simple algebra shows that the output voltage v0 is equal to -, there is a negative sign, why there is a negative sign? That is expected because you are applying to the inverting terminal, negative sign, then you have rf divided by r1 times v1 plus rf times divided by r2 times v2 and so on up to rf divided by rn times vn. So you see that this is not a simple addition, this is a weighted addition of various voltages, weighted addition.

V1 is weighted by rf by r1, v2 by rf by r2, for example you may want 0.1 v1 to be added to 10 times we do to be added to let say 7.5 times vn. Then you choose an rf, then you choose r1, r2, rn such that you get these factors. It is a weighted addition, for example you could, you may want this to be, this addition to be made. 0.1 v1 +10 v2 and so on and so forth, all right. So it is a weighted addition, weighted addition of voltages. If you are simply going to add them, then you make all resistors equal, all right. Make rf going to r1, rf equal to r2, rf equal to rl and therefore you will simply get v1 plus v2 plus vn and so on, all right.

What is the input impedance faced by v1 for example? R1, similarly voltage source faces the impedance or the resistance that is connected between it and the inverting terminal, all right, that is the input resistance. Now suppose we do not want this negative sign, we want an addition with a plus sign, what is it that we can do? You can, you can (())(26:43) inverting terminal, noninverting terminal, you can do that. What you can do is, let us find an alternative solution for us. Suppose i am stuck with this, let us say i have a chip which does this and i want to use this chip. There is a negative sign and i want to change the sign, what do i do?

Student: (())(27:09).

Professor: That is correct, you take an op-amp with -1 gain which is simply this op-amp, -, plus, this is grounded and this resistance will be same as this. So what all i do is i cascade or i connect in cascade, connect in tandem and other states like this and then this is simply a sign inverting stage. That means a stage with a gain of -1.

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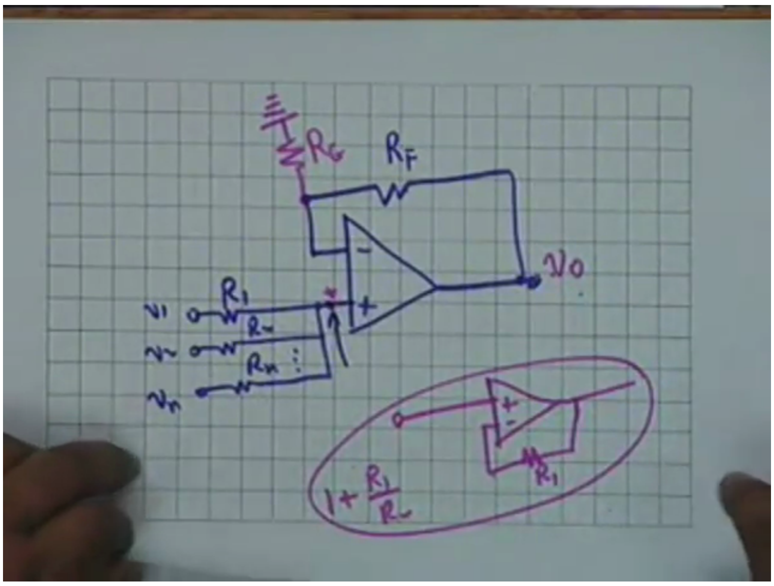

I can either do this for this i am fussy, i do not want to use 2 op-amps. Then what i will do is, what i will do is i will connect these sources here. V1, v2, vn, r1, r2, rn, then what do i do? Can i leave this open? No. Why not? That is the question i have not raised so far, i wanted to come to a certain stage. Can i for example ground this? I cannot do that because an operational amplifier, because of the high gain can never be left open circuit it. Except in very special situations, we cannot leave it in an open loop. That is we must have, we will clarify this later in great details a high gain amplifier should always be operated with feedback and feedback should be negative feedback.

Suppose i connect a resistance from here to the output terminal, you will get nothing, the amplifier will start oscillating, it will give all nonsense, it will be unstable. So there must be a feedback from here to the output, so the output is here, there must be a feedback like this. Now what will this feedback do? Suppose this resistance, i will call this resistance as some rl, what would be the gain from here to here? From this point to this point, what will be the gain? I have done this configuration a minute ago. What will be the gain from this point, from this point to this point, the gain? Plus1. So you see that this is the same circuit as this. There is an r1 but then r2, r2 is infinity, again is one plus r1 divided by r2. R1 is there nonzero but had to infinity and therefore the gain is plus1, is that clear? So what we are basically doing is we are using a unity gain stage. The addition, the addition is done right here. The addition is done right here and the gain from here to here is plus1.

If it is plus1, do i require the rf, no, i do not require, so i can as well short-circuit this. Or if you want again, suppose you do not want a unity gain, you want a gain greater than 1, then what you do is, you connect a resistance from here to ground. Suppose this resistance is g, rg, then what is the gain from here to here? 1 plus rf divided by rg and whatever the voltage addition of it, this will also be a weighted addition. I leave this to you as an exercise to find an expression for v0 in terms of v1, v2 and vn, all right. You can do it by summing up all the currents here, v1 by r1, v2 by r2 plus vn by rn what will this current be, total current?

It shall be equal to 0, all right. And what is the voltage? What is this voltage?

Student: 0.

Professor: How come? It will be v0 rg divided by rg plus rf and because no voltage can exist between these 2, this voltage shall be the same as v0 rg divided by rg plus rf. So equating these 2 you can then find out the voltage v0 in terms of v1, v2, vn, this is one method.

Another method is superposition, that is you find out the effect of v1 on v0 by killing all other sources. Killing means what? They must be connected to ground because the sources have to be short-circuited. So we find v01 due to v1 alone, then we find v02 due to v2 alone and sum all of them up.

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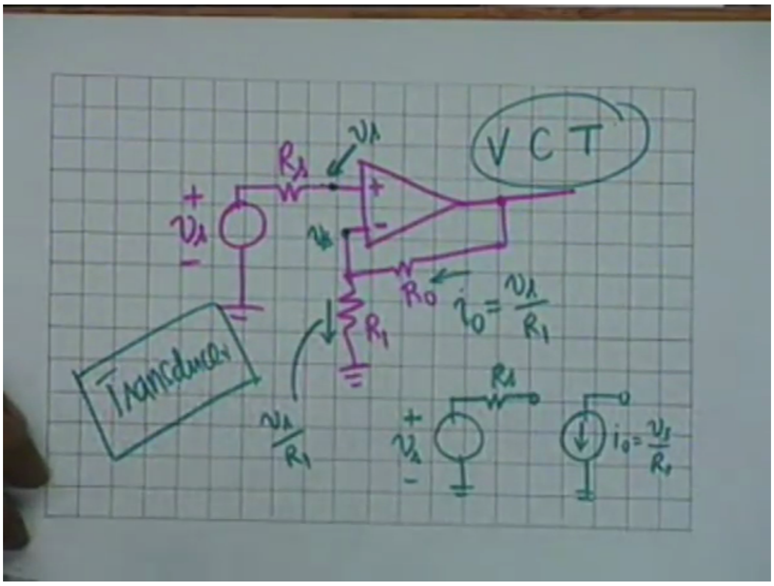

Whatever way you do, you should be able to get the current results and i leave this to you as an exercise. Let us consider now another circuit as an example of application of the op-amp. Let us say that vs, voltage source vs in connection with, in series with its internal resistance let us say rs, okay, we have voltage source in which, which is not ideal, which has an internal resistance rs and we connect it to the noninverting terminal of the op-amp, all right. As i said an op-amp cannot be left without negative feedback because then it will oscillate.

And therefore to be able to operate this, to the inverting terminal we must connect depending on what you want, you must connect a resistance from input to output and then suppose there is another resistance here and let us call this r1 and let us call this as r0, all right. Now what would be this potential? For the analysis of this circuit, what would be this potential? Vs, why because the op-amp does not take any current, so there is no drop in rs, so vs comes directly here. Is this point clear?

Student: Yes.

Professor: All right, if this is vs, then what is this potential?

Student: Vs.

Professor: Vs, then what is this current?

Student: Vs by r1.

Professor: Vs by r1, all right. What is this current?

Student: (())(34:51).

Professor: Okay, let us call this current as i 0, then i 0 is vs by r1, right. Now what is the equivalent circuit? Equivalent circuit of this is that you have a vs, it is with an internal resistance rs, it does not deliver any current. The output current i 0 is equal to vs divided by r1. All right. This is the circuit and you see that it is a voltage controlled current source, all right. So this is called they voltage to current converter, voltage to current converter. The voltage vs is being converted into a current which is proportional to vs. And the technical name for such a converter is a transducer t.

A transducer converts a physical quantity into another physical quantity. For example force could be converted to a voltage, the device that is used in a transducer. Voltage is converted to a current, both electrical quantities but the nature of the quantities are different. One is a cross variable, the other is a through variable. So it is called a voltage or current transducer or simply vct. Similarly we can have a cvt, current or voltage transducer, we shall see this later. But transducer is a general term, a transducer is a device which converts one physical quantity into another physical quantity, the 2 quantities could be quite different from each other. In that sense is an op-amp a transducer? Op-amp, is it a transducer?

Student: (())(37:12).

Professor: No, it converts voltage into a voltage but an op-amp along with peripheral circuits like this can act as a transducer. It can convert yes…?

Student: (())(37:24).

Professor: Why is i0 vs by r1? Because the op-amp does not take any current here. This current is 0, therefore whatever current is flowing here must come from here, that is a simple explanation. We shall come back to op-amp later when we have done a little bit of transistors and transistor circuit. We shall come back but as far as the laboratory is concerned, this knowledge will be sufficient to carry out experiments with op-amps.

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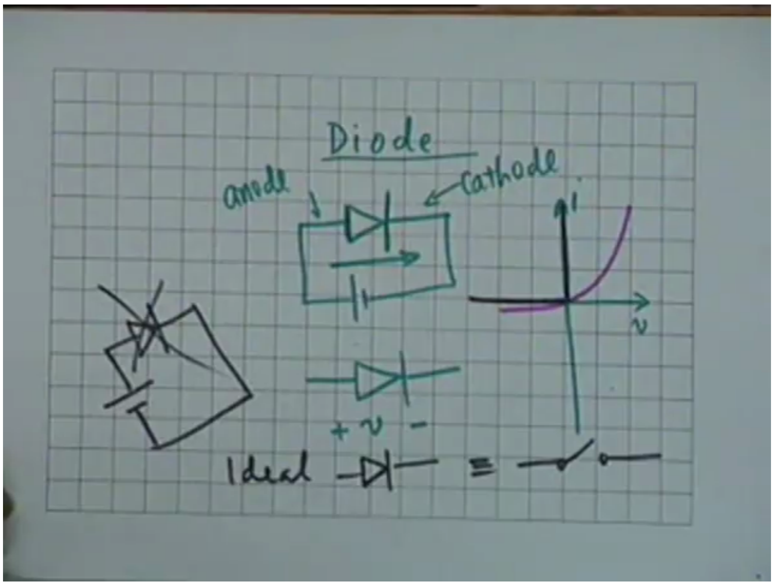

We next consider another very simple device called a diode. A diode has already been introduced as a non-linear device which conducts preferentially or in a discriminatory manner. It conducts in one direction, current in one direction more easily than in the other direction. That is a diode if it is connected like this, if it is, the symbol for a diode is this, the left side is called an anode and the right side with a vertical line is called a cathode. This is an anode, this is the anode and the cathode. From anode to cathode it conducts a current easily, this is the direction of the current.

On the other hand if the polarity of the battery is reversed, the current reduces to a very small magnitude. And as i have shown in a few classes, in a class held a few days earlier, the operating characteristics or the vi characteristics is like this. Is this voltage, yes, this is the voltage and this is the current. The current, the current flows easily if v is positive, whereas the current flows with a lot of reluctance if v is negative. This current, when v is negative, this current is negligibly small. In fact the forward current could be of the order of a milliamp and the reverse current could be as small as a nanoamp, nanoamp is 10 to the -9 amperes.

Now exactly like an op-amp, exactly like an op-amp we would like to idealise a diode. And ideal characteristic of a diode, i idealise by saying that the reverse current is 0, so the ideal characteristic is that it remains 0 like this and when v is positive, while the current increases without bounds. That is this is the ideal characteristics of a diode. Now this ideal characteristic, does not it remind of a switch that when the switch is on, any amount of current can flow, when the switch is off, no current can flow. So an ideal diode, ideal diode is equivalent to a switch.

When the diode is biased in the forward direction, that is the anode is positive with respect to the cathode, the switch is closed. When it is biased in the reverse direction, that is the anode is negative compared to the cathode, then the switch is open, no current flows and therefore if an ideal diode is simply connected, one should not do that but on paper there is no harm. Suppose an ideal diode is connected like this, an ideal diode, then the current in the circuit shall be infinite, so the diode shall burn. And there are many diodes which are very nearly ideal and one should never make a connection like this, a diode should never be connected across a battery directly.

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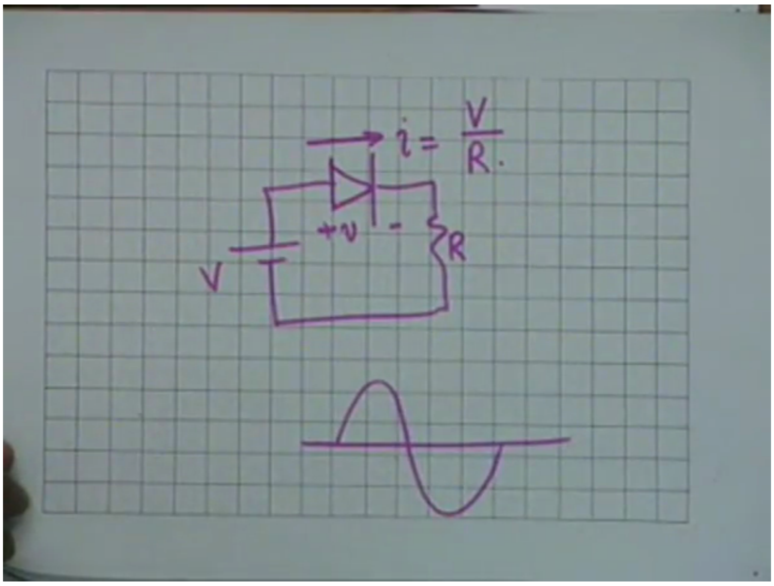

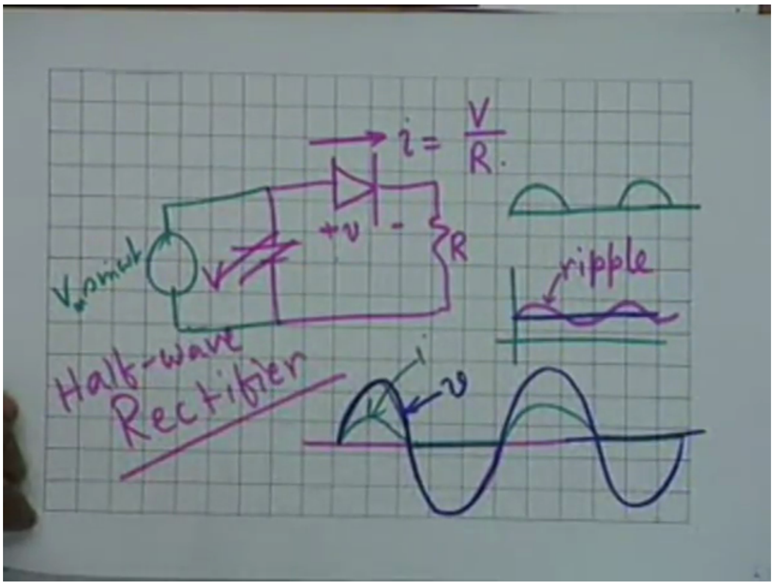

Because even if it is not infinite, the current may be large enough to burn out the diode, all right. So what then limit the current in the diode? Obviously we shall have to have an external resistor in the subject, all right. So a diode, typical diode circuit would be like this, you have voltage source let us say v and then you have an r. If this diode is ideal, then the current in the circuit would be like this and the current would be simply given by v by r because the diode in the forward direction acts as a switch with 0 resistance. We assume, what is the drop in the diode then if it is ideal, 0. The total drop shall be across r, all right.

Now this preferential flow of current in a diode is utilised to convert an ac to dc. Suppose you have an alternating voltage like this, if it is applied, if this v is replaced by an alternating voltage, let us say vm sin omega t, then the current in the circuit shall flow only during the positive half cycle, that is only during this cycle. Well the current shall be determined by the external resistor r and therefore if this is vm, if this is v, if this is v, and this is i, then the eye during the negative half cycle shall be equal to 0, is not that right?

And for the next cycle again, for the next cycle again the current shall be positive, current shall flow and then the current shall not flow. So if you have, if you have an alternating voltage like this vm sin omega t, then the current is the circuit is pulsating, it consists of half sinusoid pulses only during the positive half of the voltage. Therefore a bidirectional voltage, voltage which could be positive as well as negative is being converted into a unidirectional current. And by dropping the current inner resistance you are converting it into a unidirectional voltage. However this voltage is not, and, this pulsating, it varies. The average value of this is obviously a dc voltage, all right.

So this voltage, this voltage, let us now consider the voltage, only half cycles, this voltage can be thought of as an average voltage, as an average voltage like this one which is superimposed an alternating voltage like this, all right. We can think of like this and usually what we want is, what we want is, if we want to convert ac to dc, what we want is this violet line, we do not want this ac superimposed on the violet line. So this ac, we wanted to be as small as possible. And therefore we call this as a ripple on an otherwise calm water surface, if you make a small disturbance, then there are very small waves, this is what we would like.

We would like ripple to be as small as possible. Now a diode used in this manner is called a rectifier, it rectifies an ac voltage to unidirectional voltage, all right. A diode connected like this and since it converts only half of the wave, only half of the wave, the other half goes waste, we are not doing anything to this, other half is simply block. And therefore this is called a half wave rectifier, a half wave rectifier, all right. Now a half wave rectifier converts an ac into a pulsating dc. There is a steady component upon which is superimposed an ac, we want to get rid of the ac, all right.

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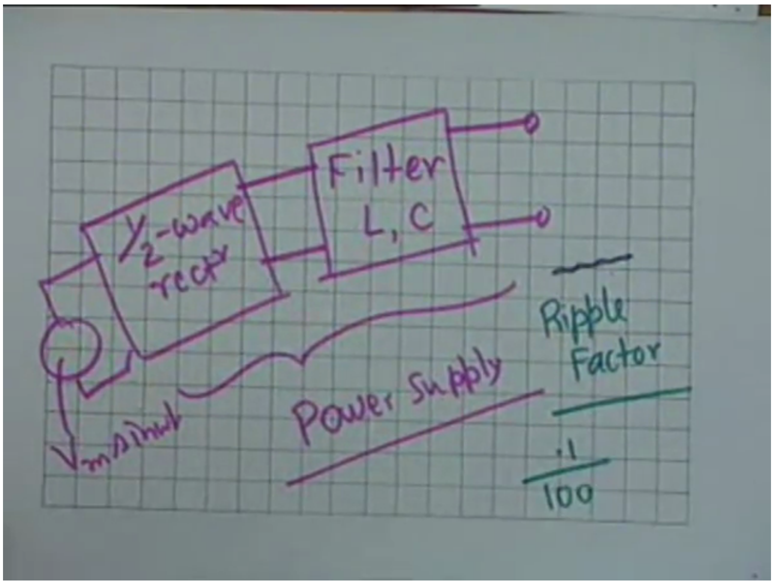

If you want a pure dc, we want to get rid of the ripple and this is done by a circuit known as a filter, a filter. That is it is a circuit which retains the dc and filters out the ac. Now the filter usually consists of energy storage elements inductance or capacitance or both l and c, it could be both. So what we do is, suppose we have a half wave rectifier, half wave rectifier, which is connected to an ac source v sin omega t, the output is fast to a filter, then the output of this shall be hopefully your dc voltage.

And this is what the power supply that you see the laboratory gives you and this combination of a rectifier, as we will see later a rectifier could be halfway or full wave, we can use diodes, more than 1 diode in a connection such that the other half, the negative half is flipped to become positive and the other half is also utilised, all right. So any rectifier connected to a filter to filter out the ac or the ripple, that will combination is called a power supply. The total combination is called a power supply, the output, the output of this hopefully would be a pure dc, but pure dc from such a combination is also an approximation. You shall always get a dc along with maybe a very small ripple, it could be let say 0.01 percent ripple, all right.

So the efficiency of such a device is characterised or measured or specified in terms of what is known as a ripple factor, ripple factor, which relates to the amplitude of the ripple to that of the dc. For example, as the dc voltage required is 100 volt, 100 volt and the ripple is let us say 0.1 volt, then we say the ripple factor is 0.1 divided by 100 or sometimes specified in terms of percentage, we simply say the ripple is 0.1 percent, all right, 0.1 in 100. Yes?

Student: The ac is rectified fully, then we talk of the, then we talk of the average value of the current, is it over the entire time period or (())(50:19).

Professor: Whenever the average value of a pulsating dc is to be found out, it is over the complete period, it is no longer a pure ac now. If it is pure ac, then the average value is 0 and for pure ac you talk of average value over half a cycle, all right. When we talk of a rectified voltage which is already unidirectional, we talk of the average over a complete cycle. And therefore it follows, a profound statement, that is full wave rectifier, the dc that it you shall produce will be twice the dc produced by a half wave rectifier, is that clear? We will look into this mathematically more details next time.