Electronics for Analog Signal Processing - I
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Lecture - 7
Diode as a Gate

In the last class, you people have been exposed to diode as an element for converting a particular waveform into another waveform, AC to DC or a triangle to sin wave; all these, clipping, clamping, wave shaping, was discussed.

Today's class, we will discuss about two other important uses of a diode: one as a digital gate, another as analog gate gate. This is an important building block in digital circuits. That is, diode as such, along with resistors, can be used for formulating two operations - Boolean operations they are called; OR operation and AND operation.

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Now, what is this? You must have been already exposed to some basics in digital circuits. We know that I can designate, let us say, 5 volts as a voltage level corresponding to digital 1 and zero volts, corresponding to digital zero.

This is called positive logic. I can assign higher voltage as digital 1 and lower voltage as digital zero. This could be any level. For example, I have now taken 5 and zero, which is the commonly acceptable level for what is called as a Transistor Transistor Logic, TTL logic family.

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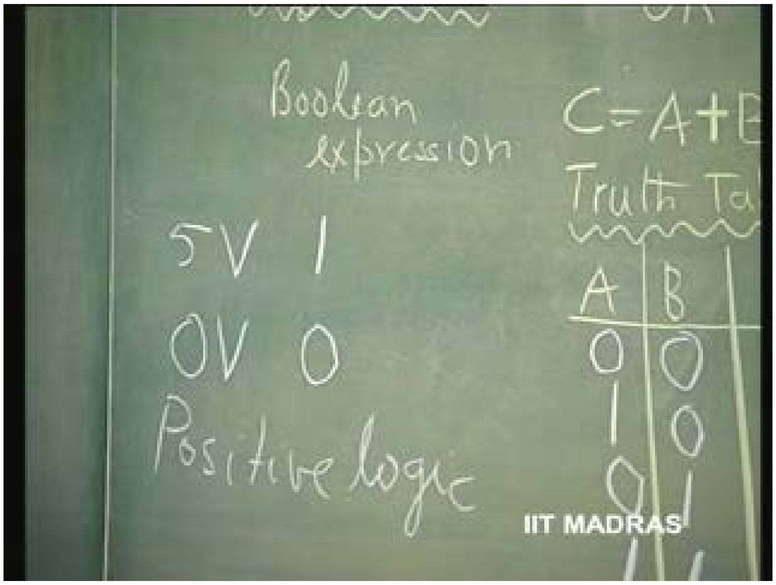

So, this depends upon the logic family that we use. So, for, let us say, TTL, it is five volts as one and zero volts as zero. If you say no, I will now select 5 volts as zero and zero volts as 1. You are perfectly permitted to do that; then it is called negative logic. That is not normally done, unless somebody wants for some peculiar design constraint, wants to select negative logic as his basic logic operation.

So here, we have chosen 5 volts as one and zero volts as zero; that is the positive logic. In such a situation, what is meant by OR operation? That is given by the Boolean expression, A ORed with B, in the sense, A plus B. This is a Boolean expression for OR operation; which means, from the Truth Table, we can find out what this real function is, when A and B, both are zero, output is zero.

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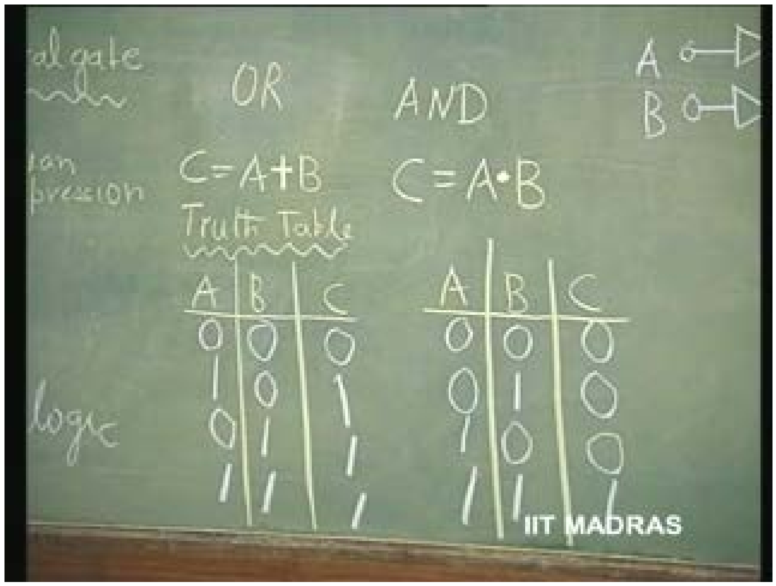

When A or B happens to be zero, and the other happens to be 1, then, output is going to be 1 in either situation; either A or B becomes 1, output will be 1. Also, when both A and B are 1, output is 1. So, output is zero only when both inputs are zero; that is the OR operation. Otherwise, output is going to be always equal to 1.

In the case of AND operation, which is, C equal to A and B, A dot B, the Truth Table is as follows: when both are zero, output is zero, as in the case of OR operation. When zero, A is zero and B is 1, or, A is 1 and B zero, both the cases, output is zero. Only when both inputs are at 1, output is at 1. A and B should be 1, in order that output is 1.

You can see the mathematics of it. Please work it out as a homework problem. Show that for negative logic, the so called this operation will give AND, and this is going to give OR, because all zeros have to be replaced by 1 and all ones have to be replaced by zeros.

So, you see that, this will look like, if you do that, this will look like AND and that will look like OR. So, you just can do that. So, AND and OR, AND and OR are going to be interchangeable in positive and negative logic.

Now, let us see the circuit that performs this operation. First, let us consider this circuit. It is a very simple circuit with inputs coming through the diode to the so called load resistance.

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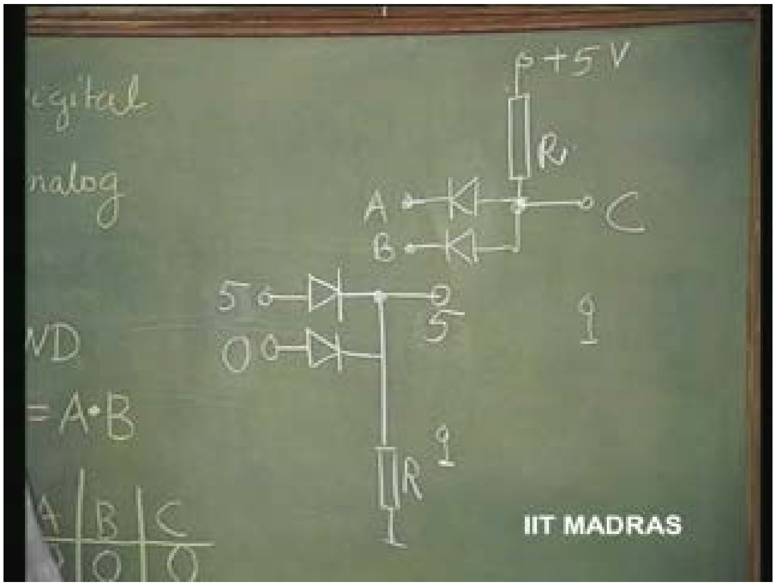

One is connected through a A through diode to R, another is connected to B through the diode and R; so, let us now consider that A and B are the inputs and C is the output.

Now, if I make A, zero and zero volts and this is zero volts, output is going to be zero, because nothing, no current is flowing in this circuit. So, the output will be same as the ground potential.

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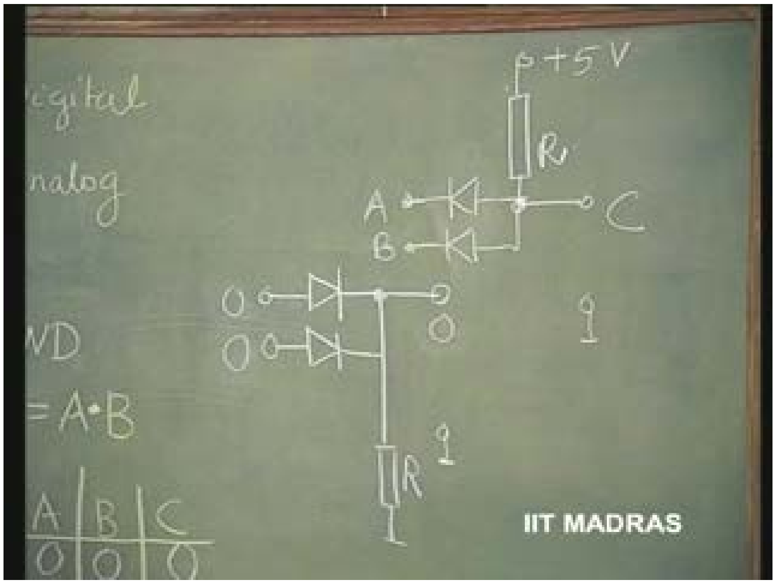

So, both A and B zero, output is going to be zero in this circuit. Now, let us make one of them equal to 5 volts, other one is at zero volts. Now, what is the output?

Now, for this, in any of these logic circuits, you have to apply logic to find out the output. Let us now consider the output as zero volts and argue out whether it is possible. If I take this as zero volts, you can note that this diode is any way not conducting zero, zero; but, this diode is conducting. So, we cannot have across the conducting diode, a voltage. So, this is wrong. So, it is wrong to assume the output as zero volts. Then, output has to be 5 volts.

Let us argue whether this is possible. Output is 5 volts. Let us consider this. 5 volts is applied. This is at ground potential; so, this diode conducts and therefore this is a short. So, it is correct that this is 5 volts. If this is at 5 volts, this is at zero volts, this diode is reverse biased; so this is off. So, this is what is going to happen.

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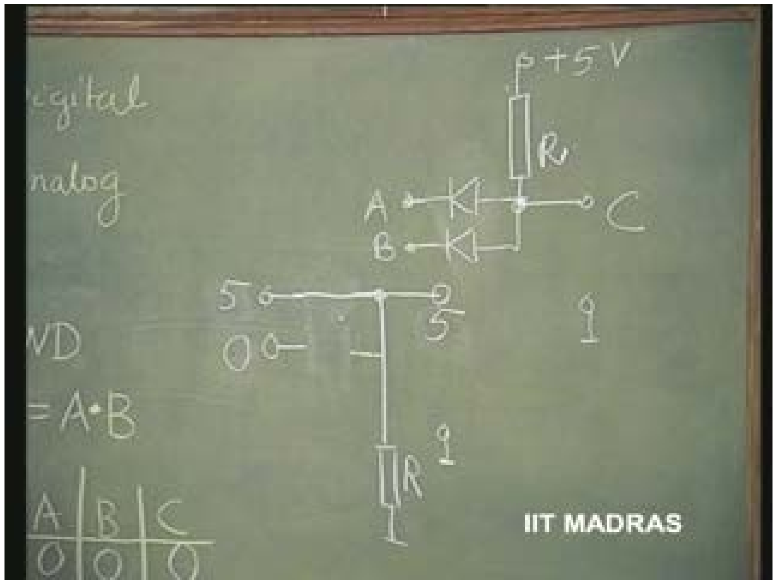

So, now, let us put down these inputs and corresponding voltages as a tabular column, A, B, C. We had earlier seen that when this is zero, this is zero, we have proved that that output can only be at zero. And now, A is at 5 volts and B is at zero volts, and we have proven that zero is not possible; it can only be at 5 volts.

Now, the other way about. When A is zero and B is 5, the same thing happens, because this, sort of this, is at zero and this is at 5. So, this diode conducts and this diode gets reverse biased. And therefore, because this is at 5 volts now, this diode gets reverse biased. So, for A equal to zero and B is equal to 5 volts also, output is 5 volts; this will be same logic.

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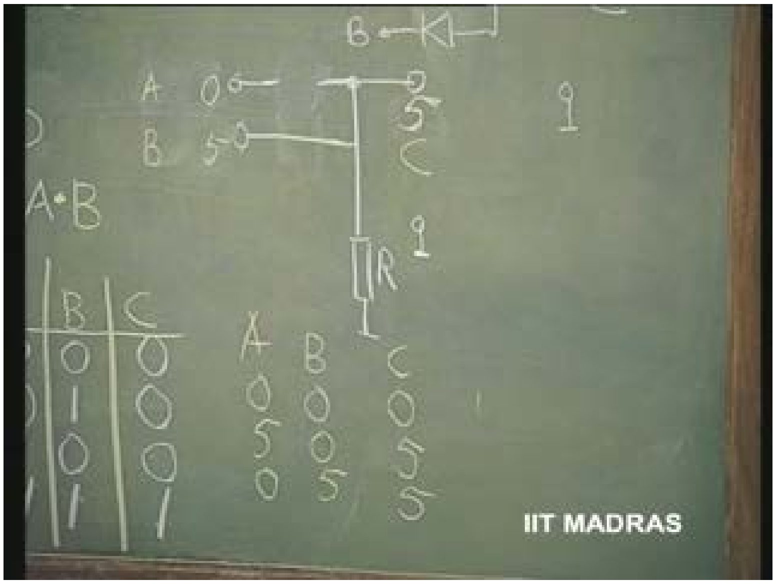

Obviously, when A is 5 volts and B is 5 volts, both the diodes will conduct, does not matter, output is going to be at 5 volts, uniquely.

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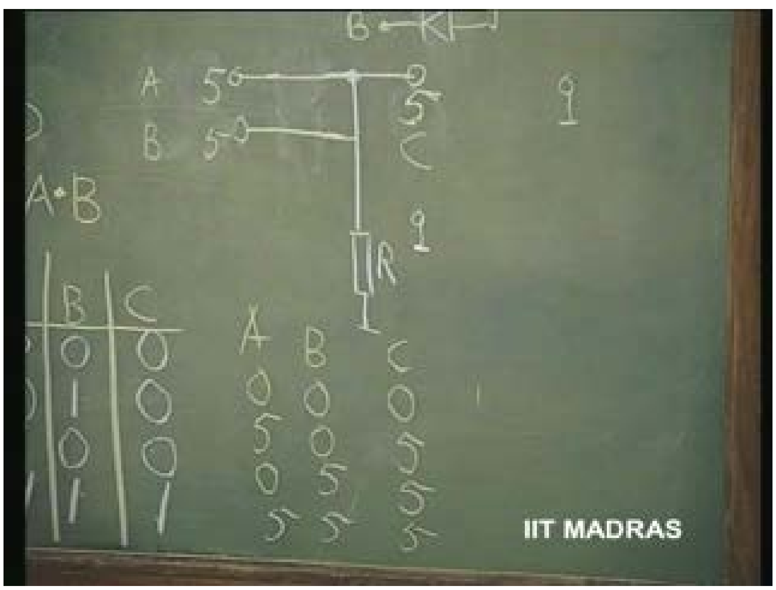

So, this can be converted into the positive logic assignment that we have given. 5 volts is one and zero volts is zero; and it becomes an OR gate there – zero, zero, zero; one, zero, one; zero, one, one; one, one, zero. So, this is an OR gate for positive logic. It will be an AND gate for negative logic.

Let us consider the second circuit here now. The diodes are connected this way and 5 volts is there, R is connected here.

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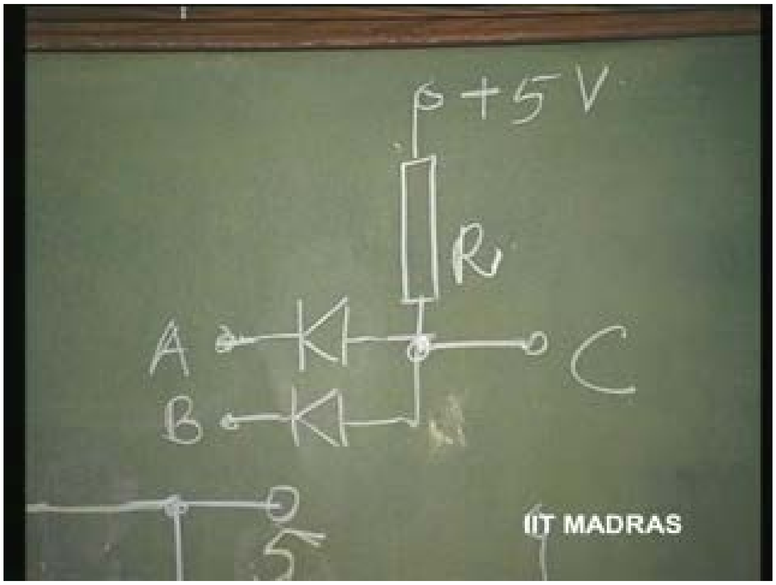

Let us consider the situation when both A and B are zero; A is zero, B is zero. So, the diodes conduct now, current will flow through this, this way, and both the diodes will conduct now. If both the diodes conduct, let us replace them by short circuits. And output C is at zero. So, A, B, C – zero, zero, zero; that is understandable. Both the diodes are conducting when the output is at zero; please remember.

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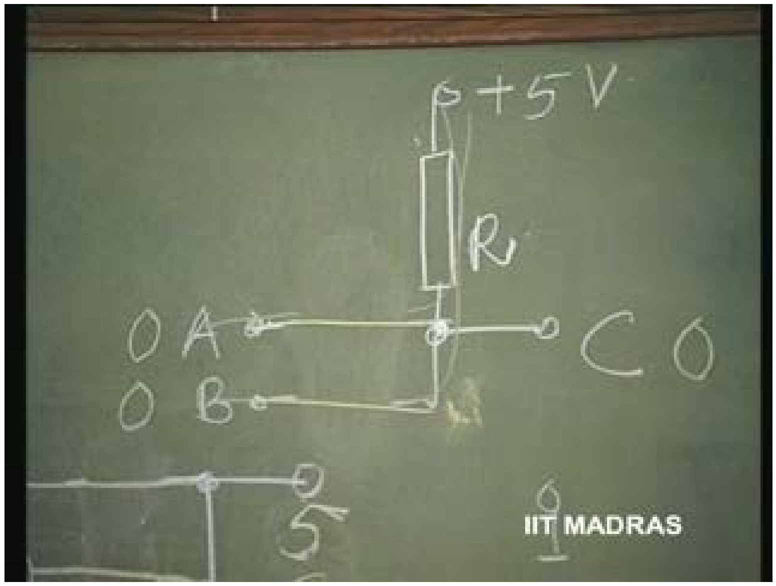

Now, we will put back these diodes. Let us say, A is zero and B is at 5 volts. Now, again, we can argue based on a logic. Let us now, for example, take C as zero; see whether it is possible. This diode conducts and it is possible that this is at zero.

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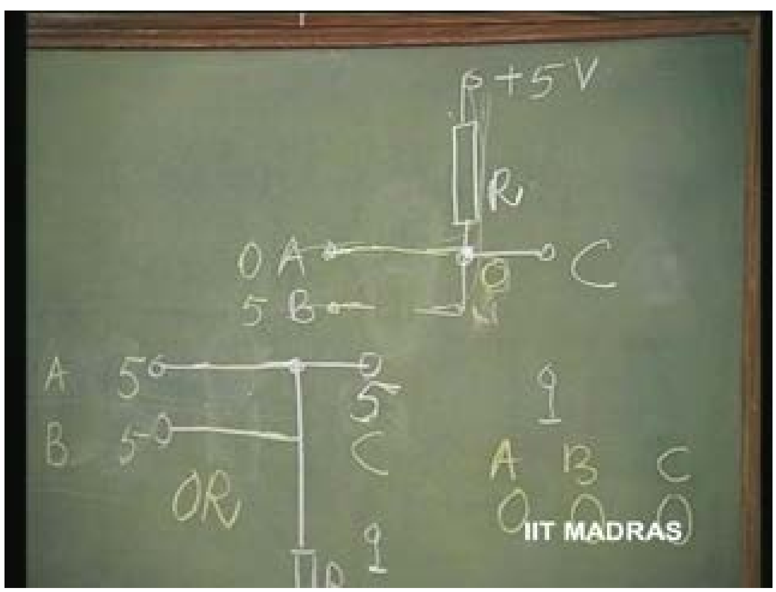

If this is at zero, this diode gets reverse biased. So, this diode conducts and it maintains this voltage at zero and this is reverse biased. So, this is possible. This is going to be an open circuit. So, output is at zero.

Now suppose, I have taken the output as 5 volts. Let us see what happens. Just for argument sake, let us take output as 5 volts. This is 5 volts, this is at zero volts. It is not possible that the diode gets forward biased and retains a voltage across it of 5 volts; it should be zero volts. So this is not possible.

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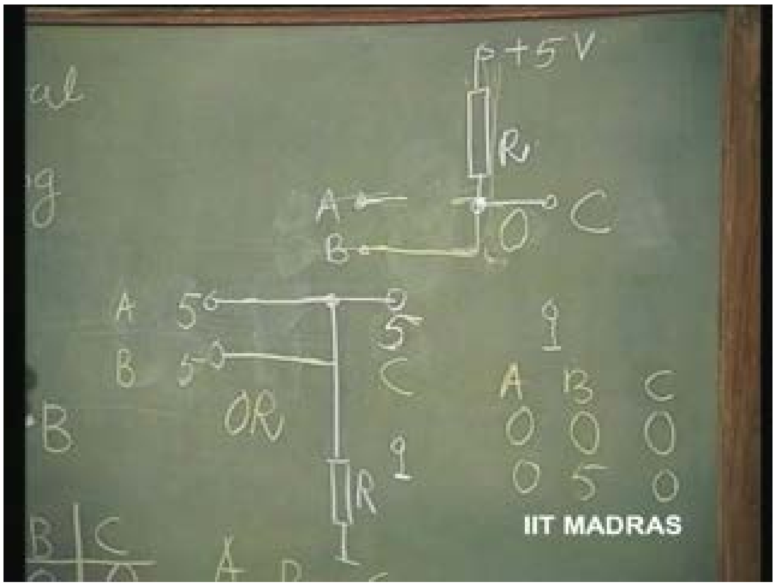

So, uniquely, you can say that the output should be at zero volts; and at that point of time, we have this diode conducting, making this a short, maintaining this at zero and this is reverse biased.

So, we have zero, 5, zero. Same argument is applicable when A is at zero, B is at 5 volts. So, let me repeat it. This is at zero. This diode conducts. This is at zero and this is at 5 volts; so, this is reverse biased. So, this is open, this is a short. So, A is at zero, B is at 5 volts, output is at zero volts.

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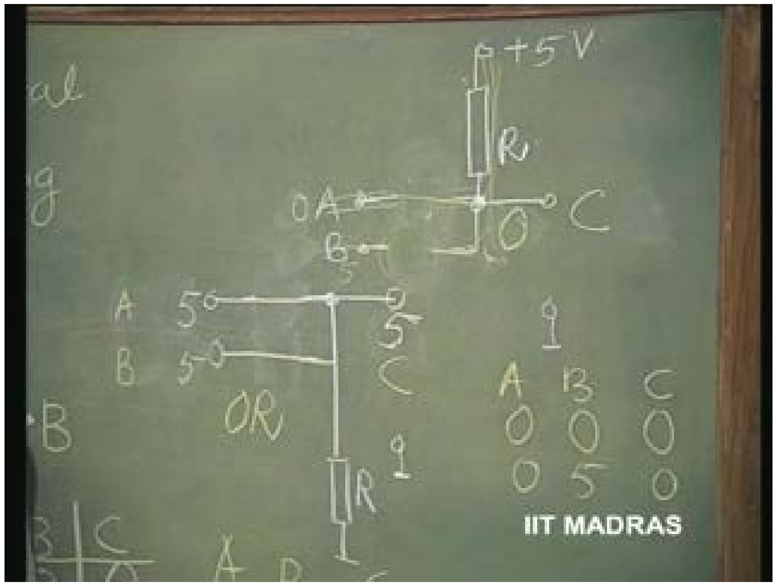

Now, the other way about. We will maintain the diodes in the original condition. We will take A as 5 volts, this as zero. Again, by the same logic, we can show that output can only be equal to zero. Let us therefore say that output is zero.

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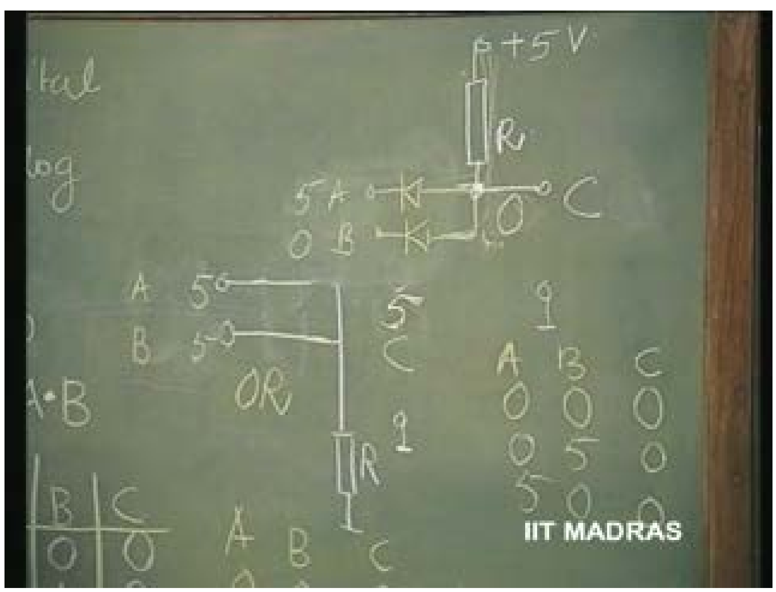

Now, what happens? This is zero, because this diode conducts now. So, this is a short and this is an open, because that is getting reverse biased. So, output has to be at zero.

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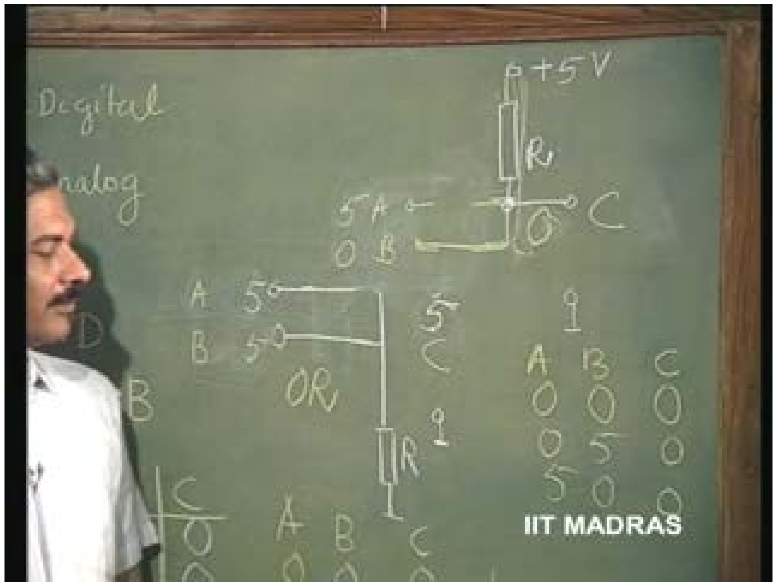

When both are 5 volts, obviously, when both are 5 volts, the entire system is at 5 volts; so, output has to be, no current flows, and output has to be 5 volts.

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The diodes, just conduct, or on the verge of conduction; and therefore, this, no current flows. This potential here is transferred to this. This is at 5 volts; so, output is at 5 volts.

So, let us now translate it into a Truth Table. Again, you see, 5 volts corresponds to 1; therefore, we have: zero, zero, zero; zero, one, zero; one, zero, zero; one, one, one, which is corresponding to an AND operation. In positive logic, therefore, this is an AND gate and this is an OR gate.

So, let us restore its hardware; two diodes connected this way. One important operation is missing in this which will complete all the necessary logic operations needed to perform any Boolean function. So, that is called inversion. What is that mathematically? A is the input; if you feed it to an inverter, output will be A bar. This is what is called an inverter; this is logic inverter; these are all logic gates.

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This cannot be performed by diode circuit. This can be performed by what is called an active element; either a bipolar transistor or a field effect transistor. These are the active elements which we will learn in the later lectures; but, you must note that this is an important operation missing here. If you have, this is also called NOT operation; inversion or called NOT operation.

What will be the Truth Table? If A is 1, A bar is zero. This is zero, this is 1. This operation cannot be performed by any method of connecting diodes and resistors. And, in the absence of this, this is not a complete set of operation.

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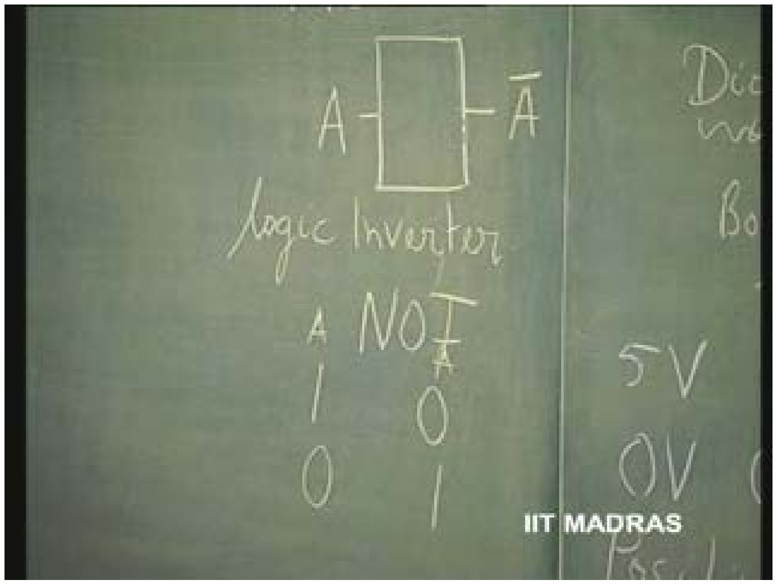

So, if I couple NOT operation with OR operation, it becomes NOR gate. I couple, NOT operation with AND operation, it becomes NAND; and NAND by itself is a complete operation. NOR by itself is a complete operation which can be repeatedly used; you can build a digital system to perform variety of digital functions.

So, we will stop at this juncture, except to give you a problem. So, this is our problem number 4. What we are going to do here is design a diode logic gate for the following function.

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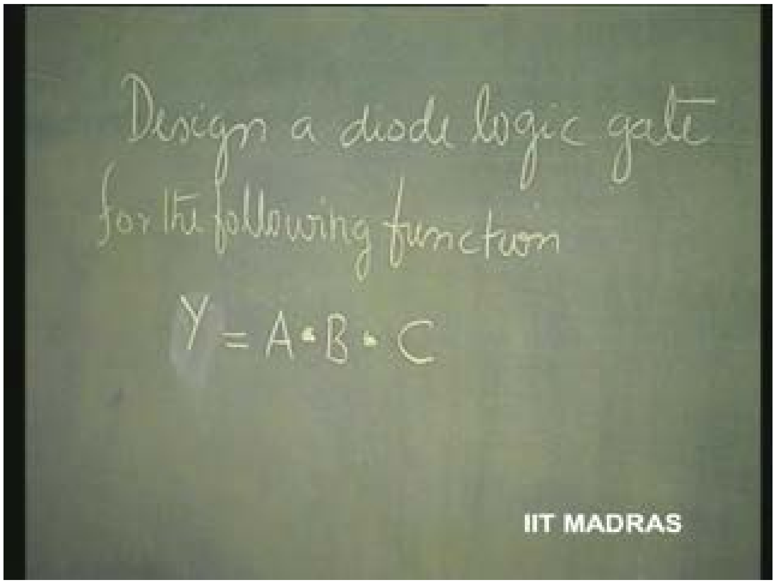

That is, C should be equal to A dot B dot C … Let us say, not C; we will put it as another variable, Y equal to A dot. So, three input. What is the gate? Three input AND gate. So, following function, this is a three input AND gate. This is the first problem.

b) Design a diode logic gate for the following function, Y equals...

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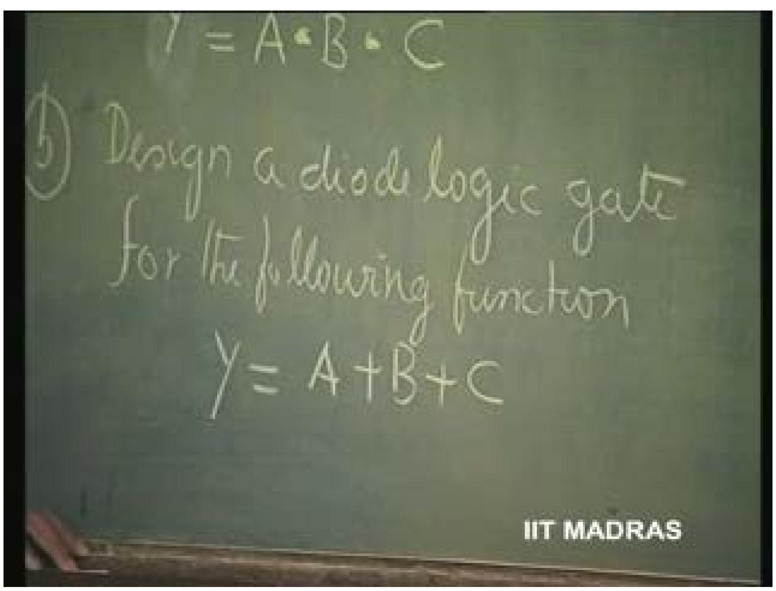

I hope that you have attempted to work out the problem that I had given you in the last lecture. Let us now see how to design a diode logic gate to give the following Boolean function. Y is equal to A plus B dot C.

So, first, we have to perform this function which is B AND C. Then, OR it with A. So, this requires a combination of two logic gates. First, let us do this B. This is a simple AND circuit that will give us B AND C as the output; B AND C.

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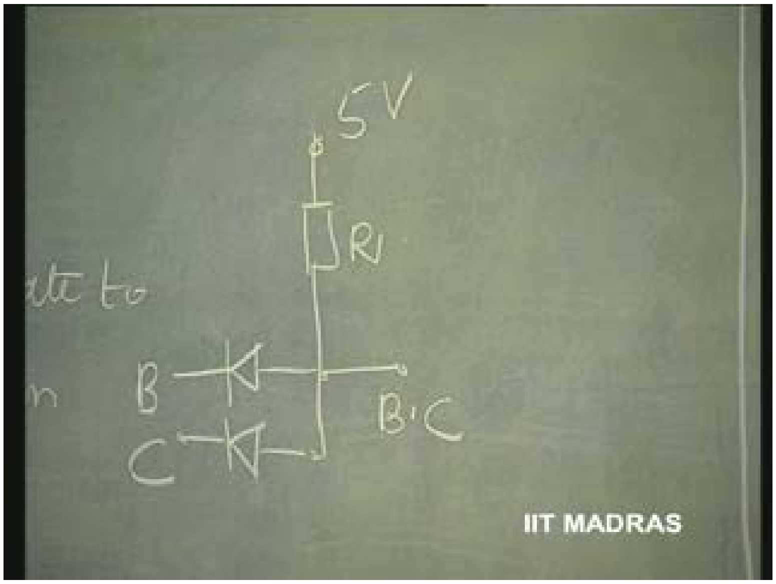

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You have got the output and that we will call this as D. That is a new variable.

So, D equals B and C. Now, you have to OR A and D. So, this D is one input to the OR gate and the other input is A. So, we have the logic variable, now, Y, as the output which will now give me, let us call this, R dash.

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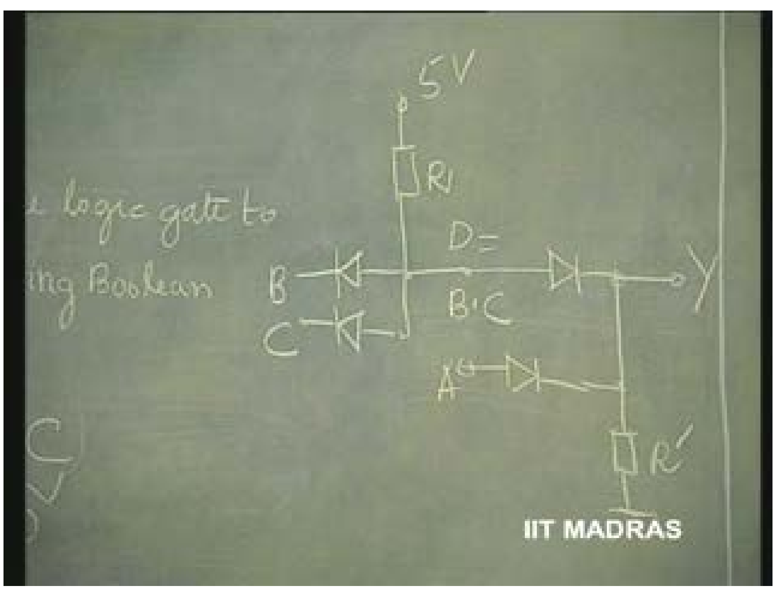

So, it is important that this R dash has to be a pretty high, so that, it doesn't load this circuit, so that, this logic level deteriorates. So, this is the schematic which will give me the Boolean function Y is equal to A plus B dot C. So, likewise, you can really sort of cascade these together to get fairly complex Boolean functions except that you will not be able to obtain any NOT operation in this.

So, now, we will go to another topic of interest. What is an analog gate? This is also called analog multiplexer. It is a very important component in signal processing.

What is the purpose of this, let us understand first. The purpose of this is, given a source, a voltage source, let us say, I would like to connect this source to a load. This is the load, this is the source, this is the load. I would like to connect this source whenever I want and disconnect it whenever I want. I should be able to control the connectivity to the source and I should be able to disconnect it.

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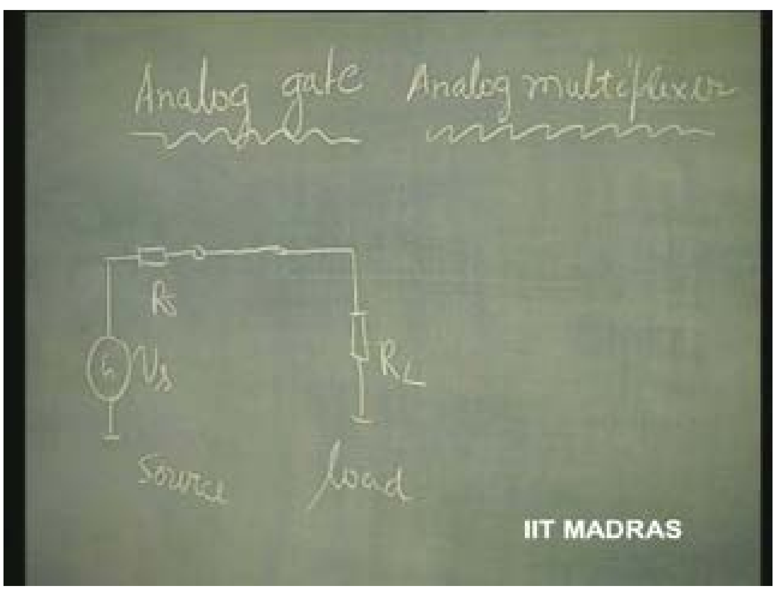

The purpose is, I might have several sources; so, when this is connected, this is not connected; and I want, when this gets connected, this to be disconnected. This is called multiplexer.

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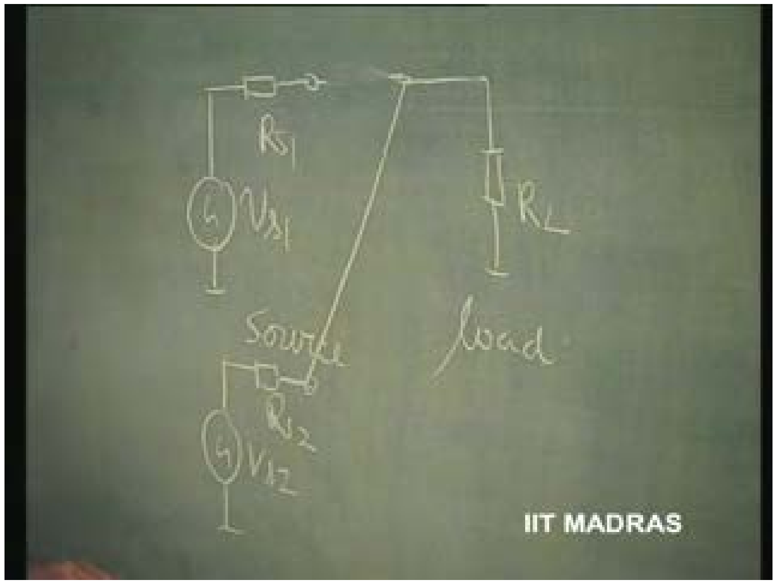

That, at certain time, I want to read this data. This may be some pressure information; this might be some temperature information. So, I would like to keep on monitoring this on a regular basis. So, what will happen? This switch will be periodically getting switched between this and this; and again, it will come back here.

You might have any number of such sources connected; let us say, ten such sources connected, which will be periodically switched by these switches one after the other. They will be sampled, and again, it will come back to the original one. This is called analog multiplexing.

This is an important operation in what is called data logging. There is lot of data to be processed, all of which come to the main terminal; and I have a digital signal processor, let us say, computer, which is going to be fed with this data at regular intervals of time. That requires first an analog multiplexer, which will sample these different analog signals and later on, this data is going to be may be digitized appropriately. So, that is a different aspect.

But the front end circuit for any such operation of a data logging is what is called an analog multiplexer; and we are now going to discuss how an analog multiplexer can be designed. This is a gate. Why is this concept called a gate? Because, this is a gate which is going to be closed when you want this signal to be permitted to flow through the diode and this is disconnected when it is not to be connected to this. So, this is like any gate.

So, this gate has to be controlled by a control signal. So, this operation of the switching, this is going to be controlled by, let us say, a control signal.

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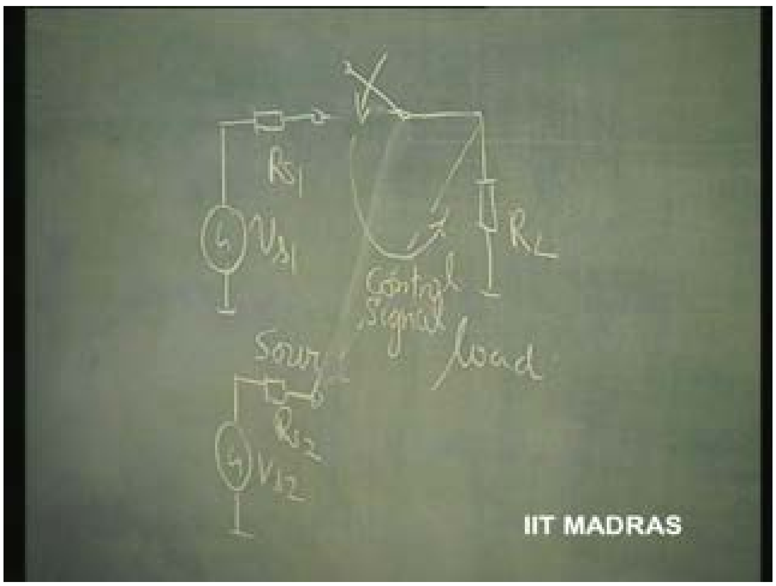

So, how to do this using diodes? Let us now come out with the circuit. Obviously, I could as well say that, I will consider first, how to connect this signal and disconnect it first, so that, when this is disconnected, I can connect some other signal. So that is facilitated, obviously, by making a diode as a switch. So, how do I make the diode a switch?

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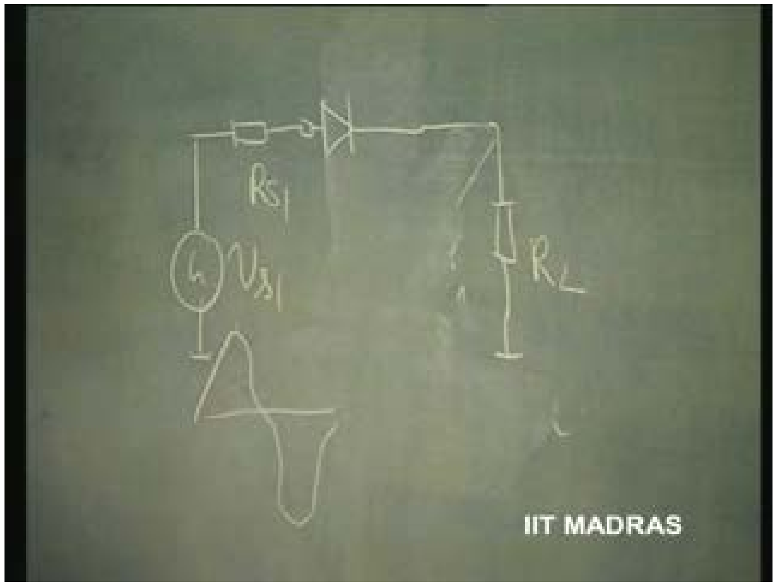

Obviously, if I connect a diode like this, you might think that it is going to conduct; but, how to prevent it from conducting? It will conduct only when this signal goes positive. When it goes negative, it is not coming.

But I want, irrespective of the signal here; whether it is going positive or negative, this switch should conduct, when I want it to conduct; and it should not conduct when I do not want it to conduct. So, for that, in fact, using a single diode is not a solution. Is it possible to come out with some arrangement where the diode is biased? The diode therefore should be biased to conduct.

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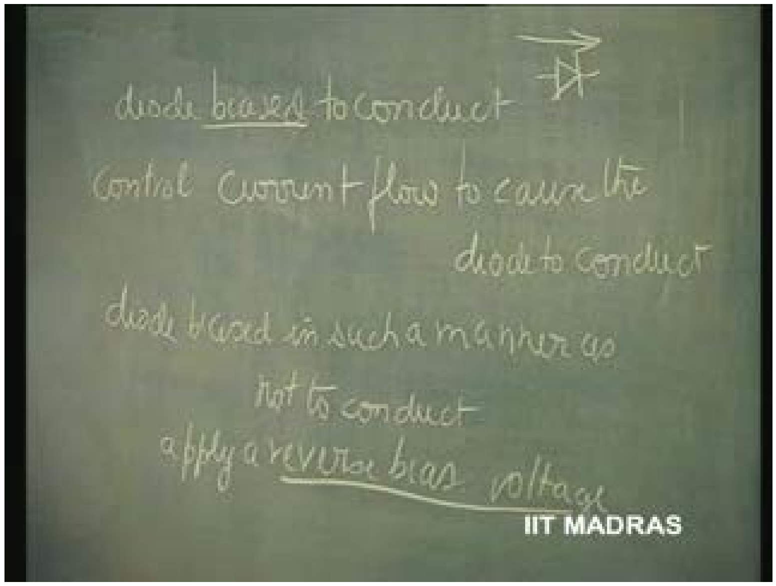

We know how to bias a diode to make it conduct. We have seen last time that by making a current flow, so we will have a control current flow to cause the diode to conduct. When I want the diode not to conduct, diode biased in such a manner as not to conduct, then, what should I do? I should apply a reverse bias voltage to the diode.

This is important to remember. I had emphasized this earlier also. I should apply a reverse bias voltage in order to make the diode not conduct. I should apply a control current to flow in the direction in it the current can flow. That is, if the diode is this way, I should be able to force a control current through the diode in this way. So, a diode is switched on by forcing a current. A diode is switched off by applying a reverse bias voltage.

It is this method that is used in building up a nice analog multiplexer using diodes. The circuit is very simple. Let us consider this circuit. Let us consider a diode circuit like this.

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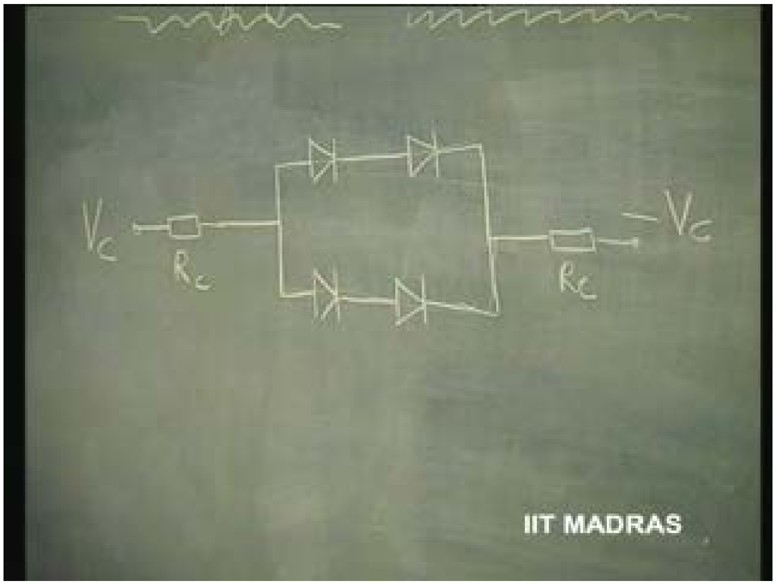

I will tell you why I am selecting a thing which is looking like a bridge. So, if I want this diode to conduct, this string of diode to conduct now, I apply a positive voltage, let us say, here V c, and here I apply minus V c.

Now, what happens? There is going to be current through the diode. All these diodes will get forward biased. So, this is going to be replaced by a short here. This is going to be replaced by a short here.

So, this is a short; this is another short.

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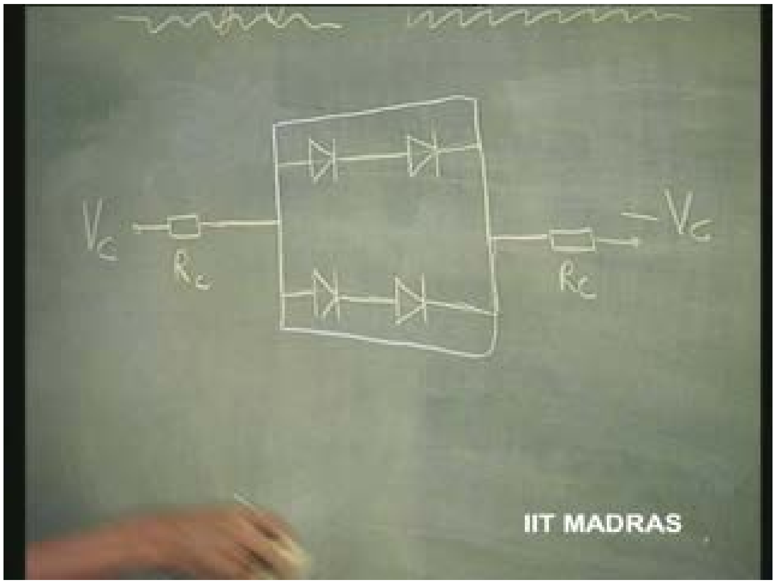

So, I can remove the diode as well and consider this whole thing as a short.

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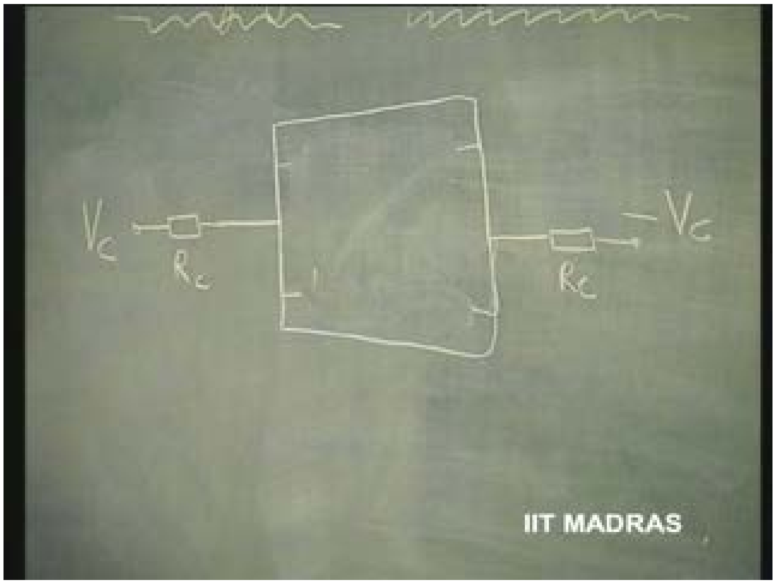

Which means, this entire thing will be replaced by a point here. The entire thing will vanish and become a point.

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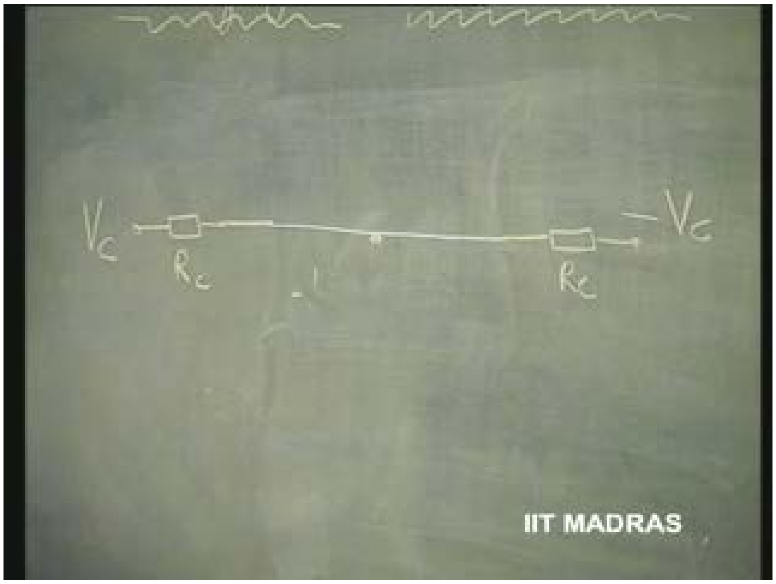

Which means, the current in this circuit is going to be V c, minus V c; that is, 2 V c divided by 2 R c. 2 V c by 2 R c. This is V c by R c.

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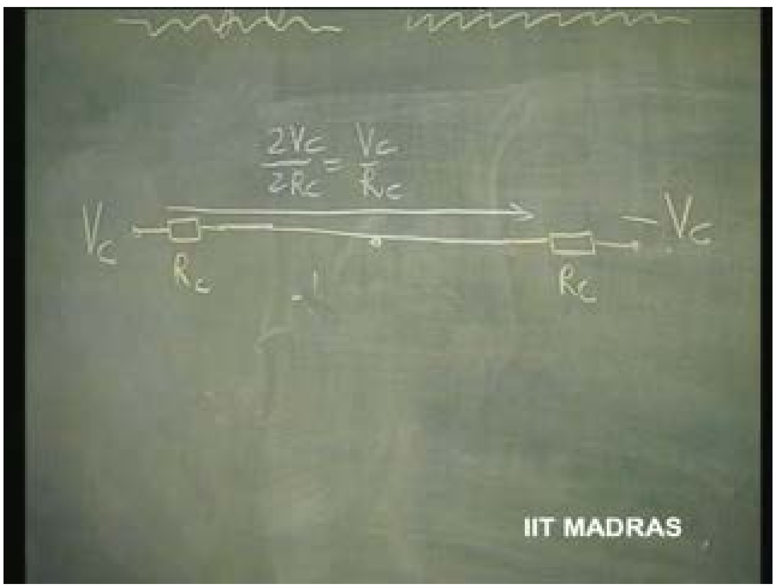

That is the current flowing in this circuit. So, once I establish the current in the circuit, I can restore the diode; only remember that, the diodes are forward biased and can be replaced as shorts. Please remember that. They are really short circuits; and the current flowing is V c by R c in this. What will be the current flowing in these respective arms? They are both short circuit. If the short circuits are exactly identical short circuits, then the current has to be half of this. This will be V c by 2 R c and this will be also V c by 2 R c. This is important that you should know what the current that is maintaining the diode in conduction is.

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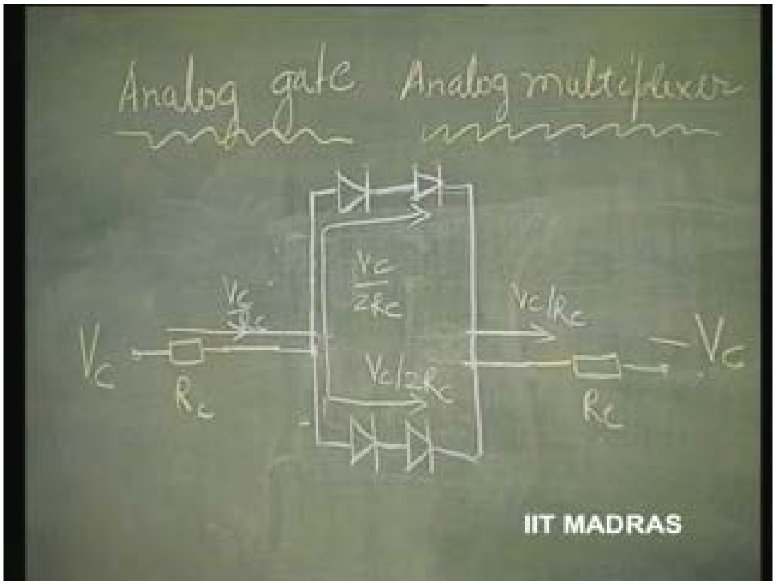

Under this situation, both these diodes are short circuits, and both these diodes are short circuits. It is a good thing that you are putting two short circuits; even if they are non-ideal, they will be better short circuits when they are in parallel. Effectively, this is a good short.

Now, I will connect this signal. Look at it. This is my original signal which I want to connect to a load. So, this is the signal and this entire thing is a short.

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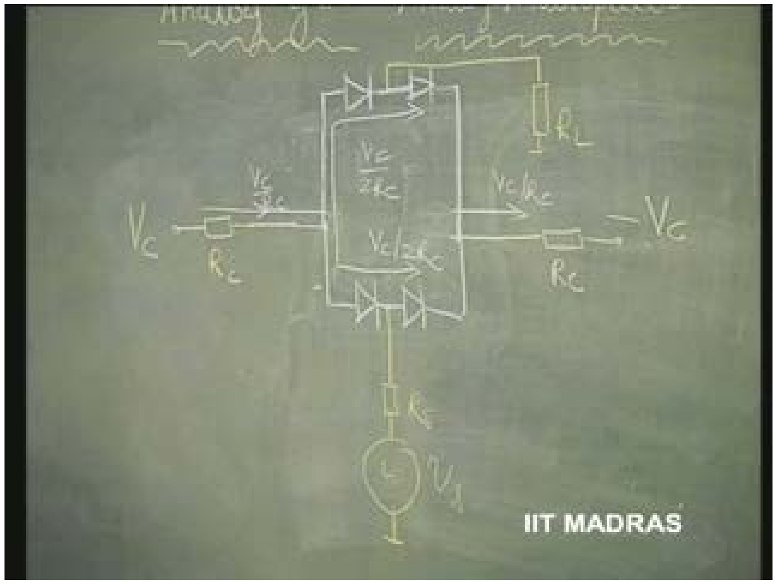

This is simply connected to the load by this process of control. Remember that this current of V c by R c is maintaining the diodes in conduction. But the moment I say that it is going to be linking this signal source to the load, the load current will flow through this. So, through the short circuit the load current will have to flow. How will it flow? Let us once again see.

What is the voltage at this point, without considering this signal source? The voltage at this point is, this is the whole thing, is a short circuit. This is plus V c and this is minus V c. This is perfectly symmetrical around this point; even if you connect the entire thing, because of plus V c and minus V c, the voltage here is going to be zero.

Because this plus V c will cause a certain voltage to appear, by superposition, if I apply minus V c on the other side, opposite type of voltage will appear and cancel out; so, effective voltage at this point is zero. So, even if I connect a resistance here and this R s here, if I do not apply a voltage here, there will not be any current in this due to V c. The current V c by R c will continue to flow in this manner. The potential at these two points will be zero; and therefore, there will be no control current in this.

Now, if I connect a signal source V s here, it can pump in a current in this direction. This is, let us say, I s, or, in the opposite direction; it does not matter. This is a signal source whose signal will go both positive and as well as negative.

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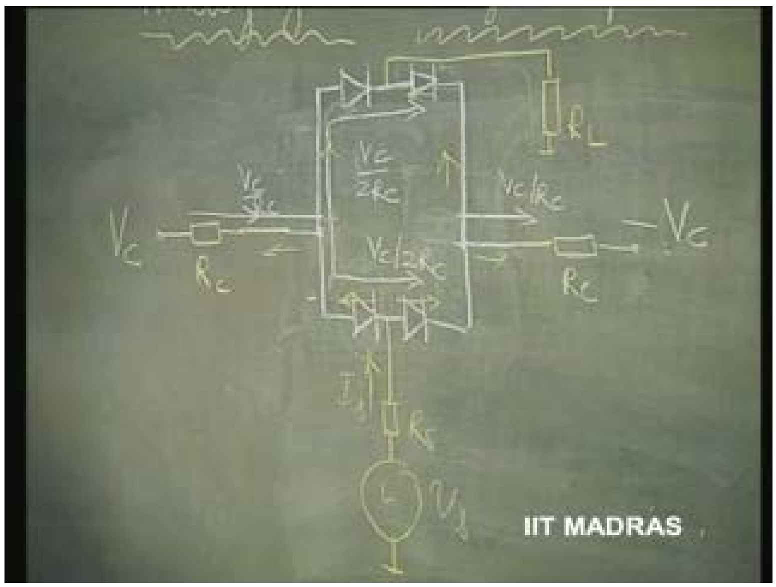

When this signal pumps in current here, the current is going to be, as far as this is concerned, we can apply superposition theorem; assume that this is grounded, this is grounded, for computing current going from here into this load; and the entire thing here is a short. So, we can say that the current is going to divide in this, as well as this, equally; and it will go here, here, here and here.

So ultimately, some current will reach this R L and develop a voltage here; not the full current, some portion of the current. So, output is going to get connection of V s to this; and some current will flow through this. That is established.

Now we can see here, as far as this diode is concerned, the control current V c by 2 R c is flowing in opposite direction to the signal current. So, this will conduct slightly less. Here, these two currents are in the same direction. This will conduct more and so is the situation here. The signal current here is going to aid this diode current and this will have the current in opposition to the control current.

But, as long as the control current is greater than the signal current, all these diodes will continue to conduct and they can be ideally replaced by short circuits. So, this circuit will function as an analog gate or multiplexer without any problem, as long as this control current continue to flow in this; and control current of any one of these diodes is not cancelled by the signal current. So, there is a maximum current, signal current that it can take of; that we will establish later, how much it is.

But it is very clear now that, as far as analysis is concerned, I can replace the whole thing; as far as signal is concerned, this by a short, this by a short; and this entire thing by a short circuit here.

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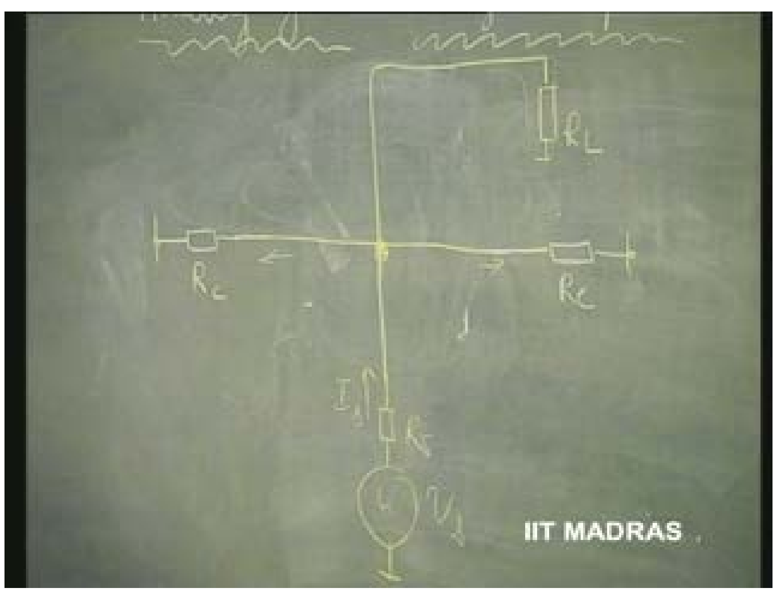

So, this is a simple signal picture, as long as the diodes are conducting. So, if that is the case, let us now see how much is the signal current. You have V s with R s coming into picture and R c in parallel with R c.

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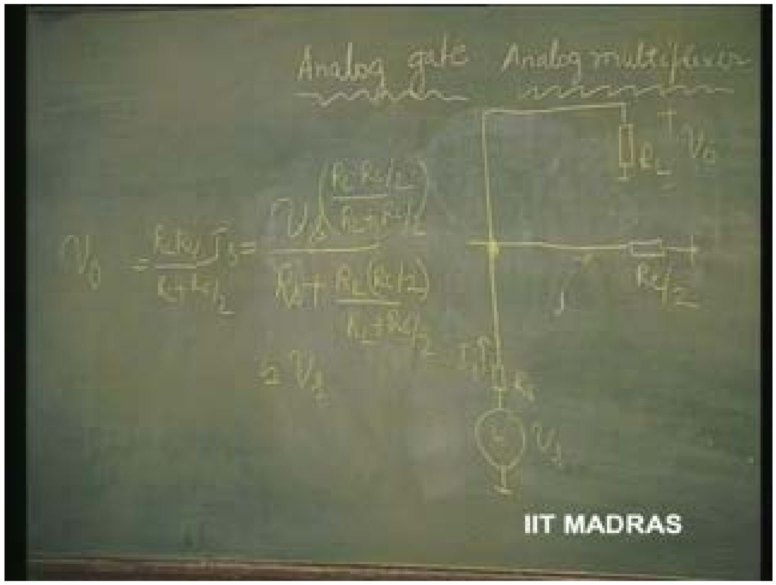

So effectively, you have R c by 2 loading this signal along with R L. So, signal current I s equal to V s divided by R s plus RL parallel R c by 2. That is the signal current that is flowing here. This multiplied by … What is the signal voltage here? This is V naught. Signal voltage is going to be therefore, this current, multiplied by the effective resistance, which is, RL into R c by 2; that is nothing but signal voltage.

You can therefore see here that, as far as R s is very small compared to RL parallel R c by 2, this is going to be very nearly equal to V s itself. As long as R s is very small compared to RL parallel R c by 2, this is going to be very nearly equal to V s itself. So, nothing is lost. So, the signal is getting connected to RL, fully.

Now, what happens to our signal if signal amplitude increases enormously? So, we have here seen that this I s is going to split equally. So, what is the value of I s? The value of I s is simply this. This is the I s. This is going to split equally into two diode branches.

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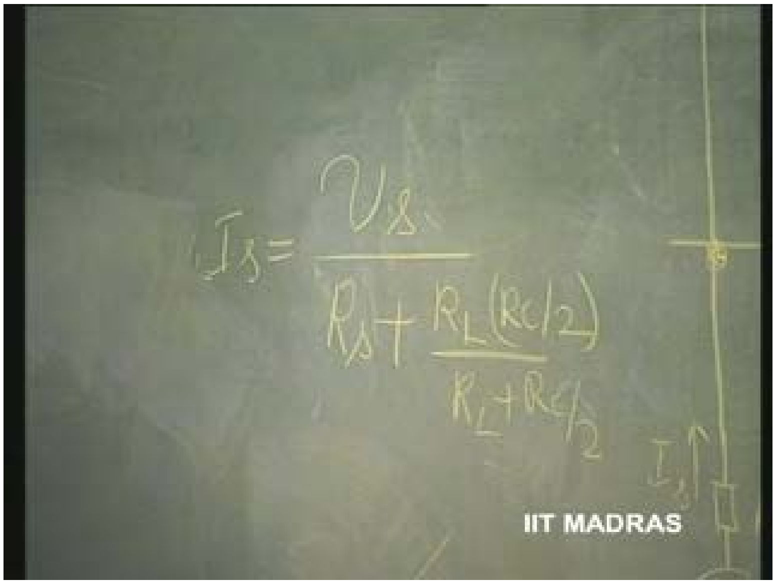

So, I s by 2 into current that is going to flow through the two diodes; in one of the diodes it is opposing; and the current in the diode is V c by 2 R c. It is therefore necessary that V c by 2 R c should be greater than I s divided by 2 at any time, in order that this circuit functions as depicted here.

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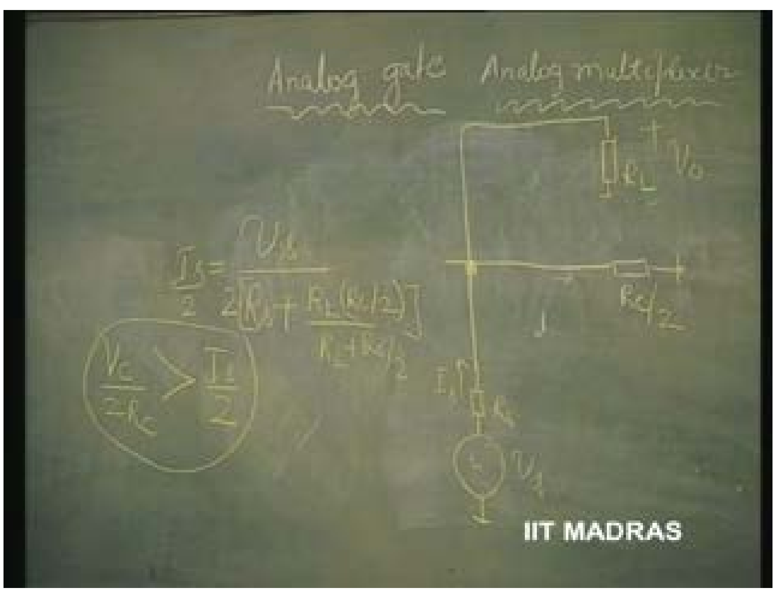

So, we can therefore find out the maximum value of V s or the most positive value of V s as well as most negative value of V s, using this equation. At all times, V c by 2 R c should be kept greater than I s by 2. If that is done, this circuit will function satisfactorily.

Now, let us consider a situation as to how to make this diode combination disconnect the source from the load. That has not been ((discussed 42:50)). What we have now discussed is how to make the source get connected to the load. This is the condition for such a thing. Now see, how to have the source disconnected from the load. That means, it should be an open circuit; which means, actually speaking, we have diodes all over. All these diodes must be now reverse biased by means of a voltage, as I pointed out in the beginning itself.

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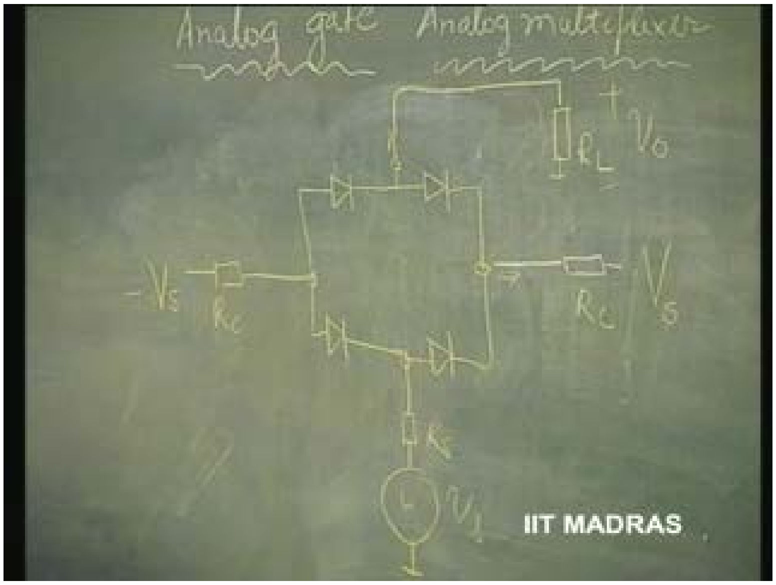

So, I simply now connect R c; this is the original circuit. Instead of connecting plus here and minus here, I simply make this V, let us say, s and this as minus V s. V c voltage here now. So I apply, plus V s here and minus V s here; and this will reverse bias the string of diodes here. What will happen? Because of my negative being applied to this terminal and positive being applied to this terminal, these diodes will be reverse biased; and all of these diodes will be open circuits. So, if this is open, this is also open, this is also reverse biased, this is also reversed biased, and therefore, now you have disconnected this from this.

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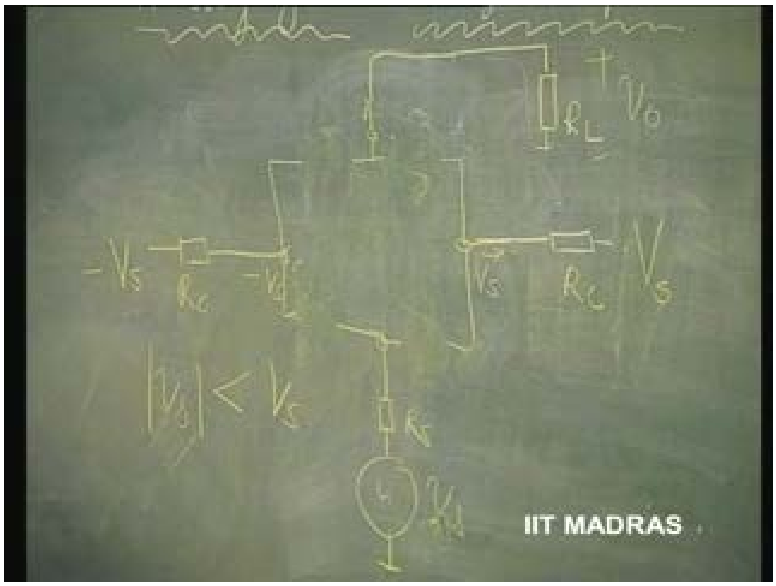

What is the reverse bias voltage? This minus V s comes here as minus V s; this is minus V s. Then, no current is flowing. This plus V s comes here as plus V s; and therefore, these two diodes are all the time reverse biased. Imagine that these diodes are existing here. So, these are reverse biased by an extent of V s; both of them. So they will remain disconnected.

Only thing is, the reverse bias here keeps changing depending upon V s. So, it is required that in order to maintain these diodes under reverse bias situation at all times, these diodes are of no concern; they are disconnected. So, if they are kept open, there is no problem. Even now, the load is disconnected from the source. Only thing is, these diodes might conduct if V s exceeds the magnitude of this - capital V suffix capital V s. So, if this DC voltage is exceeded, then, these might conduct; then also, no harm occurs.

But, we would like to have this also acting as open circuit, so that, from here to here, you have two open circuits in series; so it is totally isolated from this load. So, we will have this open as long as the V s, magnitude of V s, is kept always less than capital V s. So, this is the condition to see that the diode bridge here, this is a diode bridge, this gets disconnected when control signal goes to minus V s and plus V s. So, this is a diode bridge which is very useful as analog multiplexer.

Now, I can give you a numerical example so that things are clear. Let us assume that example. Now, we have already discussed 11. Design a diode gate to connect or disconnect a source, let us say, generating a triangular waveform at 50 Hertz with peak voltage of 10 volts.

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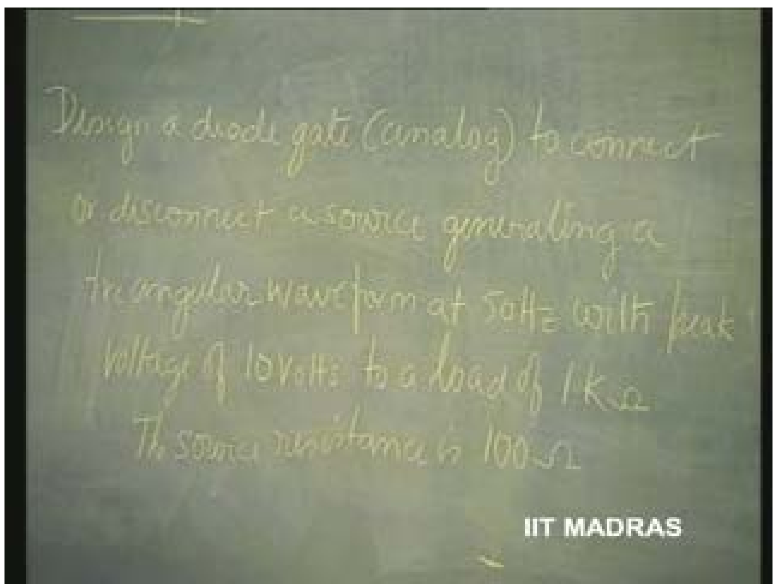

So, it is given that, to a load of 1 Kilo ohm, the source resistance is 100 ohms. So, this gives completely a data about how you want a source which is generating a triangular waveform at 50 Hertz with a peak voltage of 10 volts to be connected to a load of 1 Kilo ohm.

So, the situation is pictorially depicted. 100 ohm is the source resistance. This is generating a triangular waveform with a time period which is 20 milliseconds; 10 milliseconds here. This is 10 volts; this is minus 10 volts. The control signal, let us say, control signal is going to 1, 2, 3, 4, 5, 6. This is going to be having a time period of 20 by 6 milliseconds.

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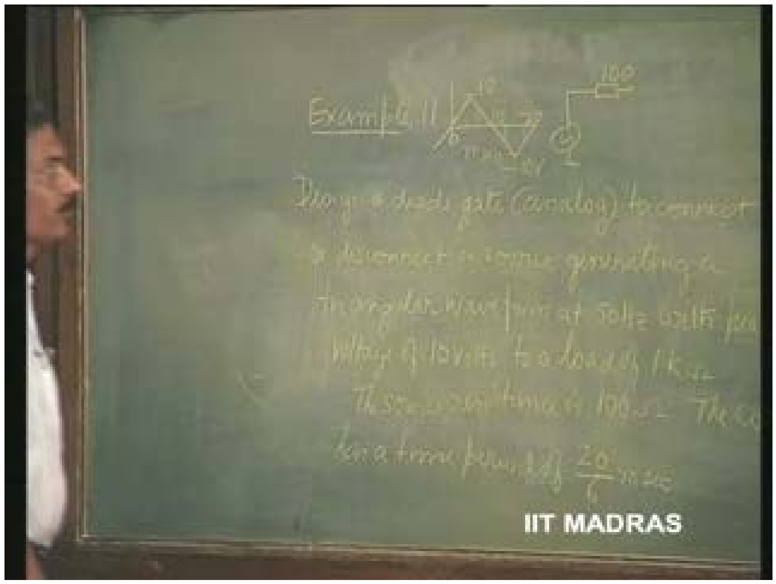

So, design means, we have to give the control signal, voltage value. How much V c is, how much V s is, what is the value of V c, what is the value of V s, and what value of R c we will put, so that this circuit functions satisfactorily, connecting this source, which is generating this triangular waveform, to a load resistance of 1 kilo ohm to solve. This gate, therefore, comes between this and this.

So, I have told you how this problem can be depicted.

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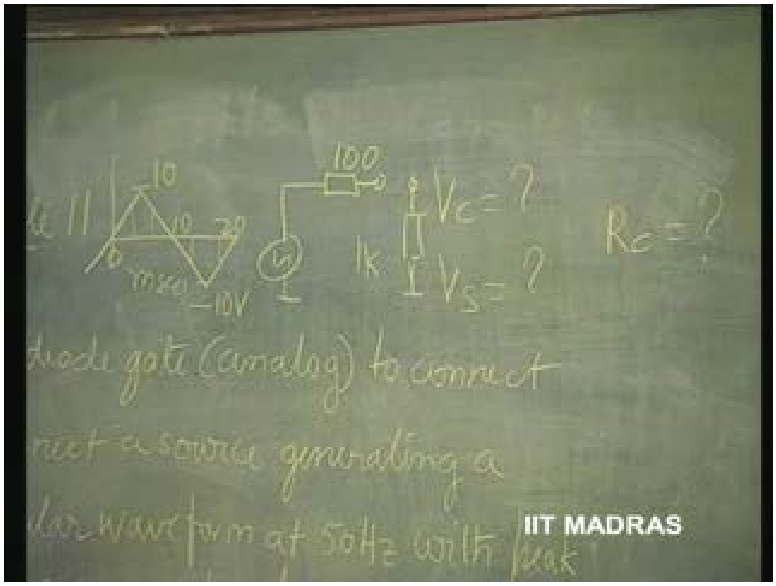

Now, in the next class, we will work this out and we can therefore think about how to solve this. Come out with your own solution. We will see how this problem can be completely worked out. I would like to add one more thing here, that, we have to draw the output waveform. After designing, you please draw the output waveform. This also, we will see. This will give us complete picture as to how this circuit functions.