Introduction to Electronic Circuits
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Lecture no 11
Module no 01
More of Wave Shaping Circuits and Introduction to Natural Response of Circuits

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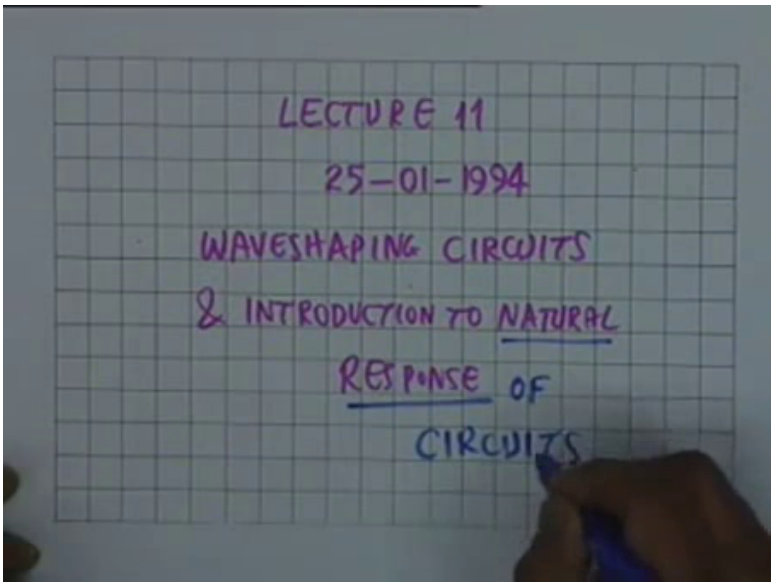

11th lecture on Wave shaping circuits and if time permits, we shall introduce the topic of Natural response of circuits.

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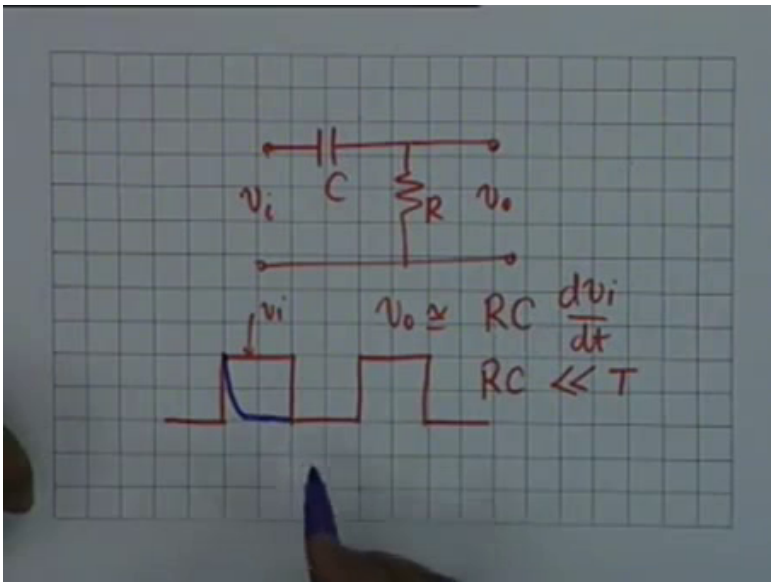

As I had talked about yesterday, we were considering a differentiating circuit C and R and if this is V i, this is V 0 then V 0 is approximately equal to R C dV i dt provided the product R C is much less than capital T, capital T denotes the time period of V i the input voltage. It is said that if the input voltage is rectangular wave like this and this is V i then V 0 will be the differentiated form and if it was ideal differentiation if it was ideal differentiation then the slope should have been infinity that should have been and impulse here and infinitely large amplitude 0 duration and there would be an negative impulse at this point, where the wave where the amplitude goes down alright.

In practice what happens is, as soon as this wave this waveform is fed here, the capacitor which was uncharged cannot change its charge instantaneously, the capacitor acts as a short and the taken voltage is dropped across the resistance R and therefore the voltage rises, the voltage across the output rises from 0 instantaneously the value V i. Then what happens, then the capacitor gradually charges so this voltage decreases, you see by KVL, V i should be equal to be V c + V 0, so when V c increases due to charging of C, the voltage V 0 decreases and this is what happens.

It rises to V i and then gradually it diminishes, it diminishes exponentially alright; it diminishes to approximately 0 till the voltage comes here. At this point at this point the voltage goes in negative direction and therefore, I am sorry I made a mistake; I wanted to take the general case of voltage which goes positive as well as negative general case.

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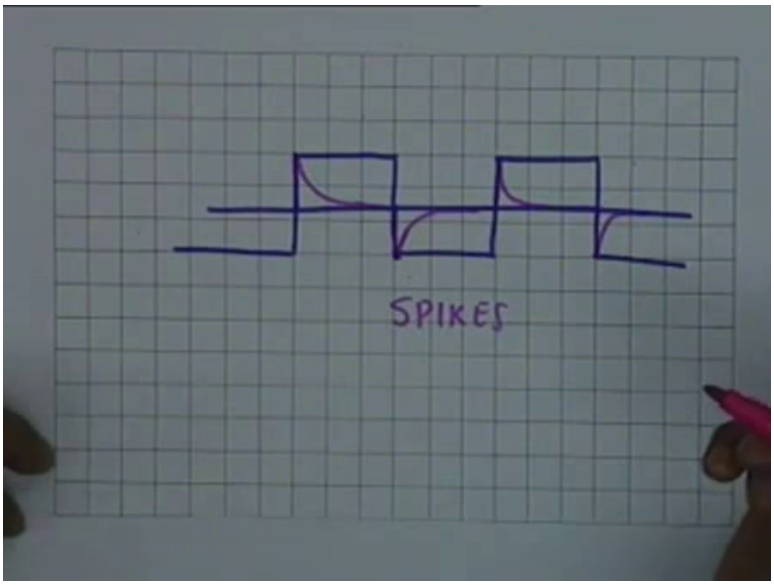

So my 0 level let us say is somehow here, this is the 0 level. But what happens is, the voltage goes up like this, it diminishes like this then when it comes here, the voltage goes down like this because the charge is approximately 0 here, once again as soon as the input voltage changes to negative level it goes to the negative level, then again it the negative charge decays which means that the voltage rises towards 0, the main (())(4:46) then again it goes up, it comes down and so on, it repeats. And these waveforms which are very sharp decay, the duration of the waveform are very small are called Spikes. So what you would absorb in the oscilloscope will be these spikes, a spike here, negatives spike here, positive spike here, a negative spike here and so on and so forth, alright, this is the differentiating circuit.

Now if you recall, in the differentiating circuit the condition under which the circuit differentiates is that V 0 should be much less as compared to V c alright, V 0 should be much less compared to V c or the product R C should be much less than T. Question is, can we obviate this constrain, can we design a circuit in which this constraint is not needed. In other words you see if V 0 is much less than V c, what it means that the output voltage is a very reduce form of the input voltage, reduced to replica, not replica reduce differentiated form. Can we do something to obviate this difficult? Well this is offered by the Op amp.

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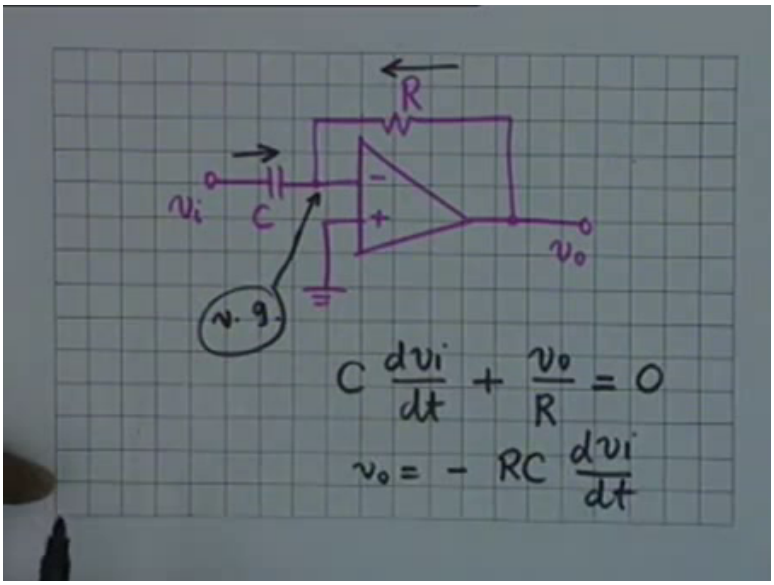

If you take an Op amp in which the non-inverting terminal is grounded, the capacitor is connected here C and the resistor is here, resistor is in the feedback path, this is V 0 and this is V i. Suppose I consider this particular circuit, then Op amp is assumed to be ideal. Now if the Op amp is ideal then you know this is ground, this point shall be virtual ground, this point shall be virtual ground, which means that the current through C would be simply C dV i dt and the current through R should be equal to V 0 by R agreed? And by KCl, the sum of the 2 current should be equal to 0 because the Op amp does not take the current, infinite input impedance and therefore you simply notice that the 0 is simply equal to – R C dV i dt and is just not involve any assumptions whatsoever.

It does not involve any assumptions about the product R C or the output voltage is much smaller compared to be V i no, no assumptions are involved. So this is a better differentiator, this is what the Op amp does, it improves, uses the same element, the capacitor and the resistor but in between we use an Op amp to improve the differentiation and this this relation if the Op amp is ideal is exact, there is no simplifying assumption involved here. This is what the Op amp does, this is the Op amp differentiator.

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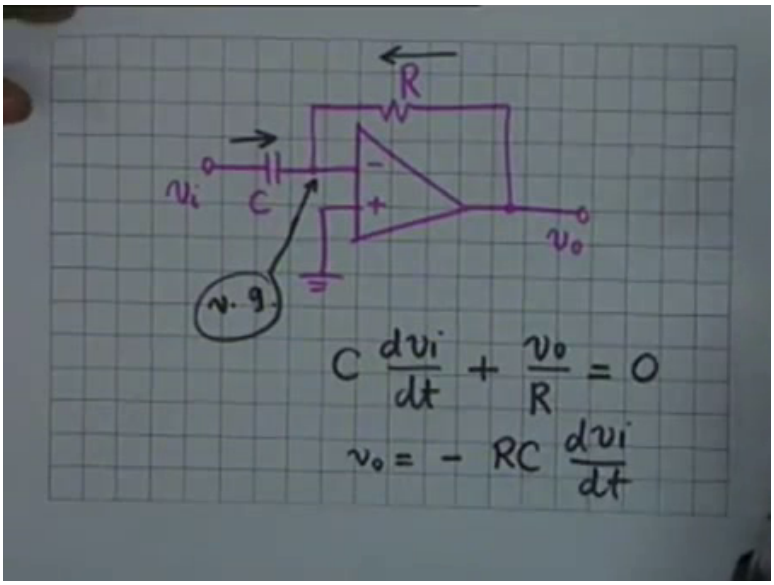

In a similar manner we can get an integrator, an integrator is a series resistance and a shunt capacitance, this is V i and this is V 0, this is the passive circuit, this is R and this is C. And you see that V 0. Yes.

"Professor–student conversation starts"

Student: Sir, in that V gs case if we increase the resistance very much large, then output voltage will also increase that means it can magnify the output voltage.

Professor: Previous case which one, in this case?

Student: In this case yes sir.

Professor: In this case if you make capital R very large.

Student: Yes, C R will increase.

Professor: C R will increase fine.

Student: So sir it may magnify the output voltage.

Professor: What do you mean by magnification?

Student: It will increase it.

Professor: You see, magnification or application the term is used when the waveforms are preserved that is if the output waveform was of the same shape as the input wave then the term amplification or magnification makes sense otherwise, if you are changing the wave shape, what is it that you will compare? The 2 shapes are different and that we do not say magnification, what I say is that the R C product now is arbitrary, there is no relation to the frequency or the time that the input waveform, alright.

“Professor–student conversation ends”

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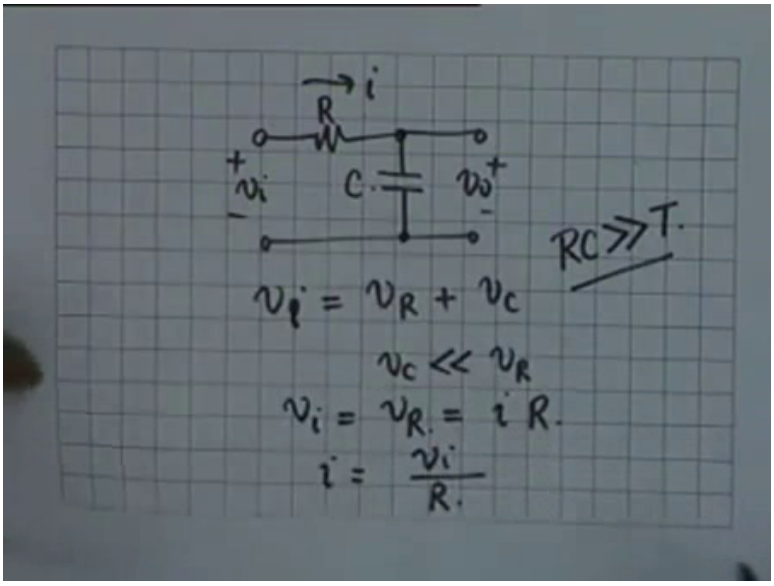

Okay, in this case in the case of the RC circuit the capacitor shunted, the capacitor as a shunt as a series resistor R, if it is exactly the differentiating circuit, you will see at the interchange, one V i = V R + V sub c and if V sub C that is the capacitor voltage is much less than V R then V i = V R, which is equal to is the current in the circuit is i, then this will be equal to i times R and therefore the current in the circuit is given by V i divided by R alright if V c is much less compared to V i and this shall be valid if if R C is much greater than T, you will see it depends on the (())(11:00) but you see that the current in the circuit is determined by resistance only.

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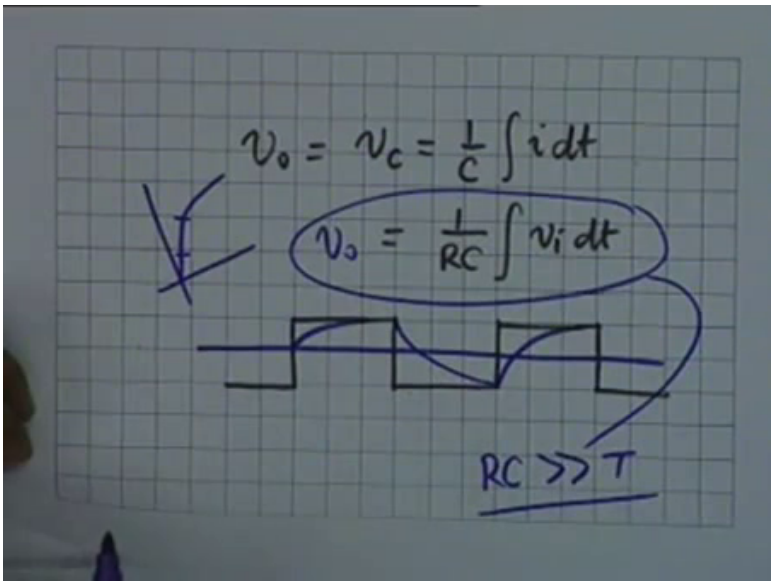

And therefore, the output voltage that is V 0 output voltage V 0 which is the same as voltage across the capacitor shall be given by Q by C that is 1 by C and Q is integral i dt, but i is V i by R and therefore this is 1 by RC integral V i dt which means that the output voltage is proportional to the integral of in the input voltage alright, therefore this is an integrating circuit, the constraint is that the output voltage must be very smallest compared to the input voltage. Now to take an example if I have a square wave once again like this like this then what happens is due to integration, well physically you can see what is happening.

Let us not going to the mathematics 1st, physically what happens you can see that when V i is applied if it is a square wave, suddenly V i rises from 0 to a value let us say capital V. The capacitor cannot change its charge instantaneously so the capacitor starts from 0 charge and then gradually gets charged alright, if sufficient time is allowed the capacitor will get charged to the maximum of V i alright. When the square wave is negative when the square wave goes negative, well the capacitor naturally charges like this, suppose if it comes from starts from here, the capacitor charges like this, when it goes negative the capacitor gets charged in the opposite direction which means that it gets discharge, so it discharges like this and once again from here from here when the voltage goes positive, the capacitor charges like this and so on.

Ideally this should be straight lines, if we are really integrating then what is shown as Violet lines which are curved parabolas not parabolas, they are exponential rises, ideally they should be

straight lines, they will be approximately straight lines if the time of charging and discharging is small is not it right? For an exponential curve like this, if you consider a small portion, well it can be considered as line as a straight line and therefore, it would be approximately an integrator if R C is far far greater than T that if the time available for charging and discharging is much less compared to time constant of the RC circuit, this is the physical explanation of a passive integrating circuit.

Now, the relation V 0 equal to 1 by RC integral V i dt is valid if RC is much greater than T and this restriction exactly like the differentiating circuit can be removed can be removed if you use an Op amp, let us feel how this is done.

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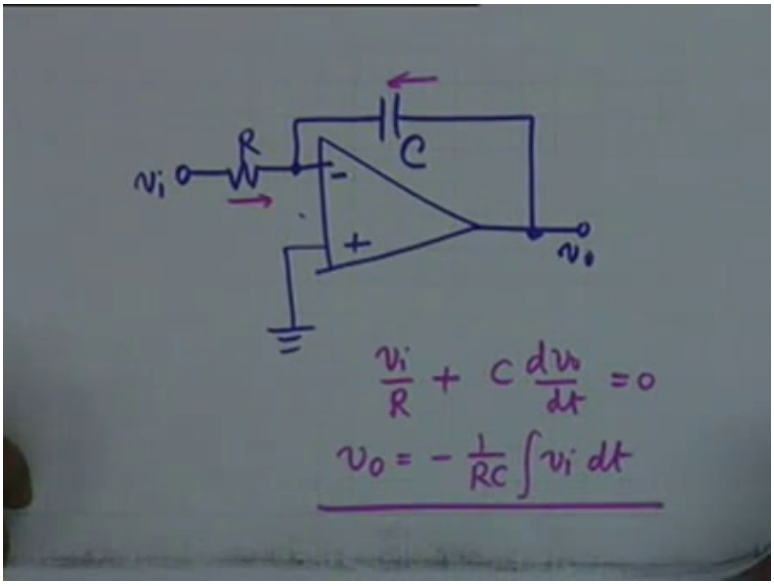

We have an Op amp, once again the inverting terminal is grounded, to the non-inverting terminal now you apply a resistor and in the feedback part you insert a capacitor C, this is V 0.

“Professor–student conversation starts”

Student: We applied it to the inverting terminal... inverting terminal.

Professor: Inverting terminal that is correct, we apply to the inverting terminal not to the non-inverting terminal no.

“Professor–student conversation ends”

Now you know that if this is R and this is V i then this current is V i by R and this current will be C dV 0 dt, the reason being that this point is virtual ground V g and therefore this current is V i divided by R and this current is C dV 0 dt that is the potential difference between these 2 points is we 0 and therefore the current is C dV0 dt and the sum of the 2 should be equal to 0, which means that V 0 would be equal to – 1 by RC integral V i dt agreed. And there is no assumption about the RC product here, there is no assumption and therefore this is a much better integrating circuit as compared to the passive integrative circuit, then example now.

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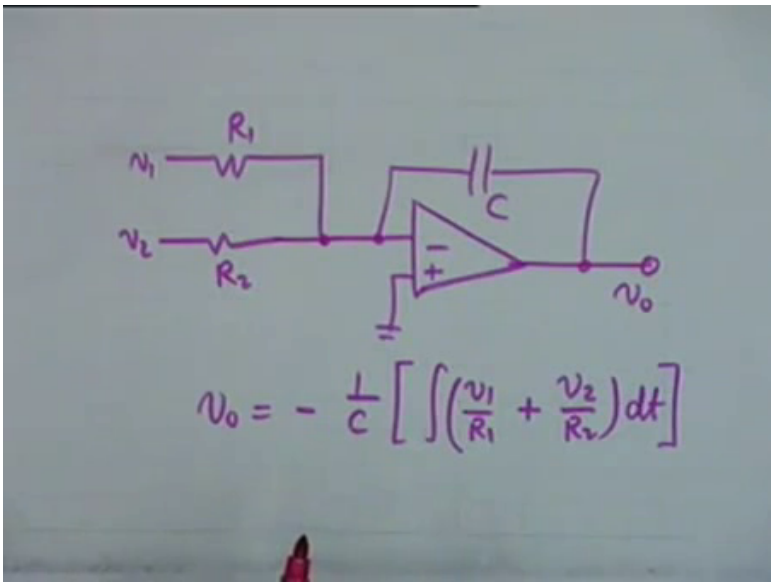

Suppose I have a resistor R 1, voltage V 1, voltage V 2, resistor R 2, two voltages alright. And what is so we have the Op amp and the capacitor C here. What do you think the voltage would be the output voltage? It can be obtained by super position and can be written down my inspection, it can be written down by inspection, it would be – 1 upon C alright the resistors are different and therefore we get integral V 1 upon R 1 + V 2 upon R 2, this will be the total current multiplied by dt alright, we have written this down my inspection. Consider a couple of more interesting examples, is this okay?

Student: Yes.

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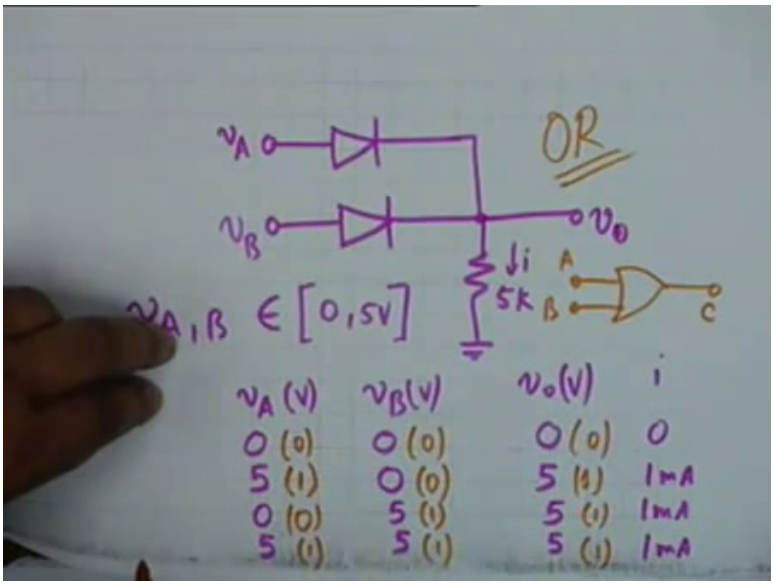

Okay, suppose we have 2 voltages V A and V B connected through diodes and that the wave shaping and therefore we are working out a couple of examples, and this is connected to ground through a 5 K resistance and this is the output V 0. This is V A let us say and this is V B, the stipulation is this is the given circuit alright, 2 diodes, 2 voltage sources, one resistor and the output is V 0 alright. It is specified that V A and V B can have only one of 2 possible values; V AB can be either belongs to the set 0 volt or 5 volt alright, V A can be either 0 volt or 5 volt.

Student: 0 to 5 volt.

Student: 0 to 5 volt.

No, just two discrete levels, either 0 volt or 5 old that means I have a 5 volt battery which I either connect or disconnect, if I disconnect the voltage is 0 if I connect the voltage is 5 alright. Both of them could be + 5 volts, both of them could be 0, you are required to tabulate the possible combination of V A and V B and the corresponding outputs, you see V A, V B and V 0. Suppose V A is 0 and V B is also 0, then V 0 shall be equal to 0. If V A is 5 volts and V B is 0 then V 0 is 5 volt, the resistance does not affect the voltage. You see if V A is 5 volts then this diode conducts, if this diode conducts the drop is 0 therefore, this voltage must be 5 volts, is that okay? Similarly if VA is 0 and VB is 5 once again this is 5 in volts, if both of them are 5, it will still be 5.

What will happen to the current through 5K? Look, suppose I find the current I find the current under all these conditions just a minute... Suppose I find the current under all these conditions that is the current i, here it will be 0, here it will be...

Student: V 0 by 5.

Professor: That means 1 milliampere, here 1 milliampere here...

Student: 2 milliampere.

Professor: No, it has to be 1 milliamperes because the voltage is 5 volts, the current is still 1 milliampere, half of which is delivered from V A and half from V B that is basically there are 2 batteries now, each battery will now give 0.5 milliampere alright? Now, this is the rediments of logic of digital circuit alright. You see, is 0 volt is considered as 0 level logic 0 level logic then 0 0 leads to 0 and if 5 volts is considered as 1 level in Digital in terms of digital circuits, 5 volts is considered as logic level 1 then 1 and 0 gives you 1, 0 and 1 gives you 1, and 1 and 1 gives you 1.

So this is an OR gate this is therefore an OR gate that is either of the 2 input levels are high, either of the terminology is high and low; 0 is called low and 1 is called high, so if either of the 2 terminals is high then the output is high, if both of them are high output is high, if both of them are low then the output is low and the traditional symbol for this is, there are 2 inputs A and B which are basically voltages V A and V B there are 2 inputs and the output is let us say C then C is low if A and B both are low, either A or B or both are high then output is high and this is the function of the OR gate or OR logic and this is one this is demonstration of yet another application of the diode in logic gates a very simple logic.

“Professor–student conversation starts”

Student: Sir, why do we need diodes here?

Professor: Why do you need diodes... Suppose we do not have the diodes...

Student: In the case when one of the inputs is low then we need the diode.

Professor: We cannot do that, we cannot make gate without diodes without a non-linear unilateral circuit that is a circuit which passes current in one direction only, you can try other combinations you never get an OR gate.

Student: Sir, what is the use of 5K resistance?

Professor: What is the use of 5K resistance...

Student: The current to flow.

Professor: The current has to flow; the current has to flow because you see if 5K resistance is not there, when I simply connect a 5v battery here, what does this 5 volts battery do? It does not do anything, these voltages will still be 0 unless the diode is shorted, for the diode be shorted the current must pass alright, you have not connected 1 kilovolt here nothing will happen here till you provide the path for flow of current then the diode will drop and you get the total voltage here, is that okay? Let us take another example slightly tougher

"Professor–student conversation ends"

The question is, I will read the question. The output of a flow meter, the flow meter is an instrument to measure low that is the rate of flow or the total flow of typically let us say a liquid, a flow meter typically may consists of a fan shaped mechanical gadget which may put in the path of flow in the path of flow, it rotates in the magnetic field and generates an EMF which is typically measured to be able to indicate the amount of flow that is rate of flow alright, this is called a flow meter, so a flow meter basically develops a voltage across it, alright.

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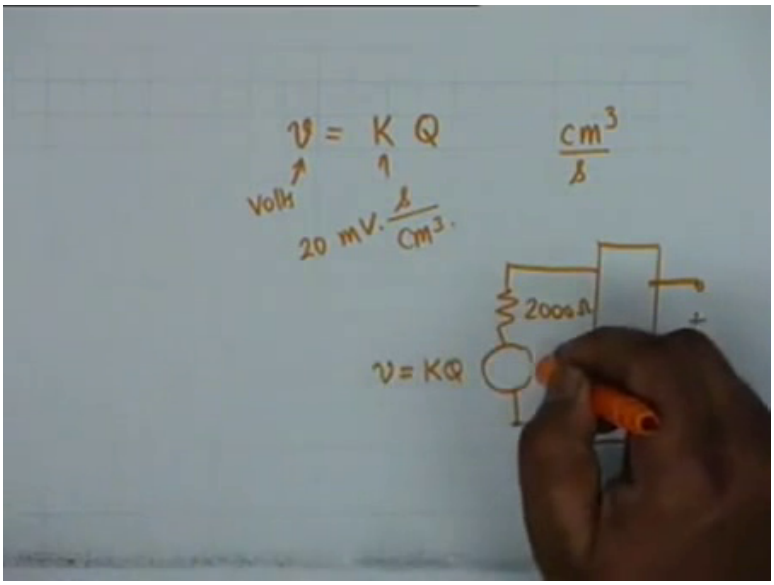

The flow meter the output of a flow meter is given by a voltage V which is equal to K times Q, where capital Q is the rate of flow that is capital Q is let us say in centimetre cube per second cc per second, this is rate of flow and capital K if v is in volts then capital K would be in volts seconds per centimetre cube, K is given as 20 millivolts second per centimetre cube this is what is given alright. A flow meter which is characterised by this relation small v = K Q, K is given like this. The effective output resistance of the flow meter, flow meter has resistance because it consists of coils rotating in the magnetic field, the coils have resistance and this resistance is 2000 Ohms 2K.

If a flow meter is represented by voltage generator then the voltage generator is K Q and its internal resistance is 2000 ohms alright, the effective output resistance of flow meter is 2000 ohms. Design a circuit that will develop an output voltage of 10 volts, you have to design a circuit that will develop an output voltage of 10 volts when 200 cc has passed through the metering point that is the total flow, when the total flow is 200 cc 200 centimetre cube, is the question clear? You have a flow meter which develops a voltage v = K Q, Q is the rate of flow and this voltage is not simply acts like a voltage generator, it is a voltage generator with an internal resistance of 2000 Ohms, what you have to do is to design a circuit connect a circuit such that when the total flow is 200 cc, the voltage develops should be 10 volts, now what does this mean?

Student: Integrating circuit.

Professor: Integrating circuit, alright let us see if we can do that.

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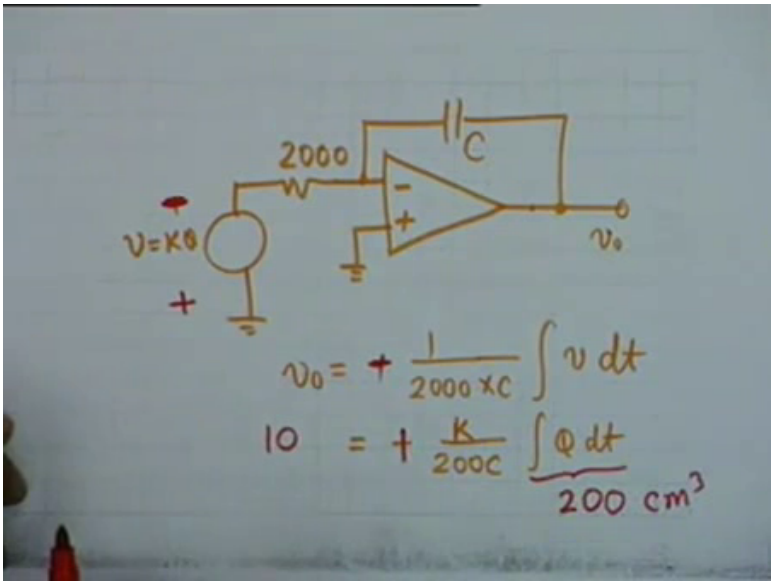

What we have to do is v = K Q, I am not indicating the polarity right away we shall see this, 2000 ohms, for this the resistance is already there so why do not you use an Op amp where this will be grounded, we have to use a capacitor C here capital C and this is V 0.

Student: Sir, why do you only the inverting terminal of Op amp, we can use the non-inverting terminal also so why we use inverting terminal?

Professor: There is a reason the non-inverting terminal, anything connected from the non-inverting terminal to the output causes positive feedback, positive feedback is like if a half (()) (29:01) person is on a sagging bridge and you remind him that the bridge is sagging, while he makes sure that the bridge goes down is this known to you, no? Okay. Positive feedback encourages oscillation and once oscillations start the circuit will produce nonsense, it will not act in the manner that you like.

For operation of an operational amplifier negative feedback is a must and therefore we make a preferential treatment of the inverting and non-inverting terminal, in most of the applications you will see non-inverting terminal is not touched, preferably it is connected to ground. We do all

operation with the non-inverting terminal, if in anything I connect from the non-inverting terminal to the output causes negative feedback and therefore it stabilises the gain, you could not do this in the positive feedback, this is a practical point and you must remember this.

Alright, now the point is that V 0 is the result of integration. You get is that in this circuit V 0 is equal to – 1 over R C 2000 multiplied by C integral V dt alright, integral V dt, which is equal to – 1 over 2000 C while V is K Q, so K integral Q dt provided our polarity are like this. Now we do not want negative voltage, we want positive voltage and therefore what we do is instead of connecting like this we want a + sign here, so instead of connecting flow meter like this we connect it in the opposite direction then this sign shall be this is okay this sign shall be positive, is that okay?

Yeah.

And integral Q dt what is given is the 10, V 0 should be equal to + 10 volts when integral Q dt that is the total flow is 200 centimetre cube therefore, all that is required to find out is the value of C the capacitance.

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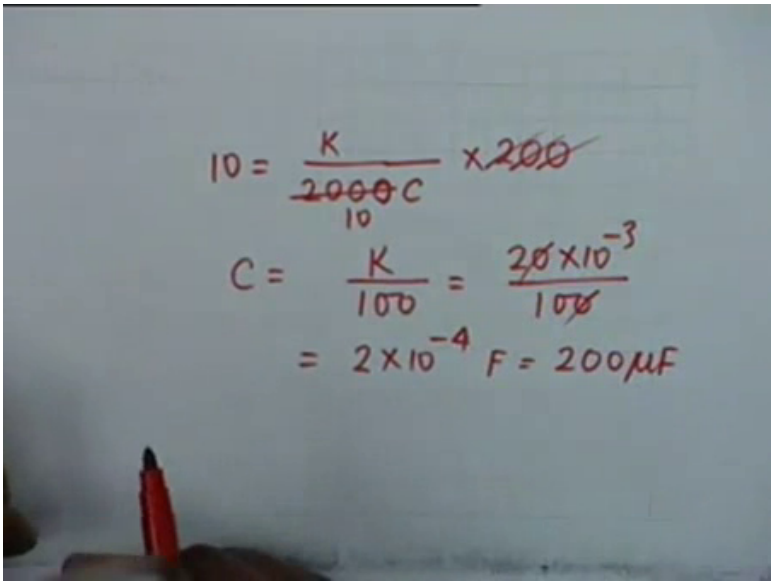

And if I clear this out of fractions, we get 10 as equal to K divided by 2000 C multiplied by 200 and K is therefore C is, take this 200 out, left with 10 so C should be equal to K divided by 100

and K is 20 millivolts that is 10 to the – 3 centimetre per second cube divided by 100 so it is 2 times 10 to the – 4 Farad, which is equal to 200 microfarad and the solution is complete.

“Professor–student conversation starts”

Student: Sir, could we use resistance in place of capacitance?

Professor: Could we use resistance in place of capacitance, then it will not integrate, it will simply be the inverting amplifier which is not what we want, we want the voltage to be developed when a certain amount of liquid has flown and this voltage is required to be 10 volts, we cannot use a resistance here no.

Student: Sir for integrating and differentiating circuits, can we develop a circuit where we use inductor instead of the capacitor?

Professor: Quite so, we can do that.

“Professor–student conversation ends”

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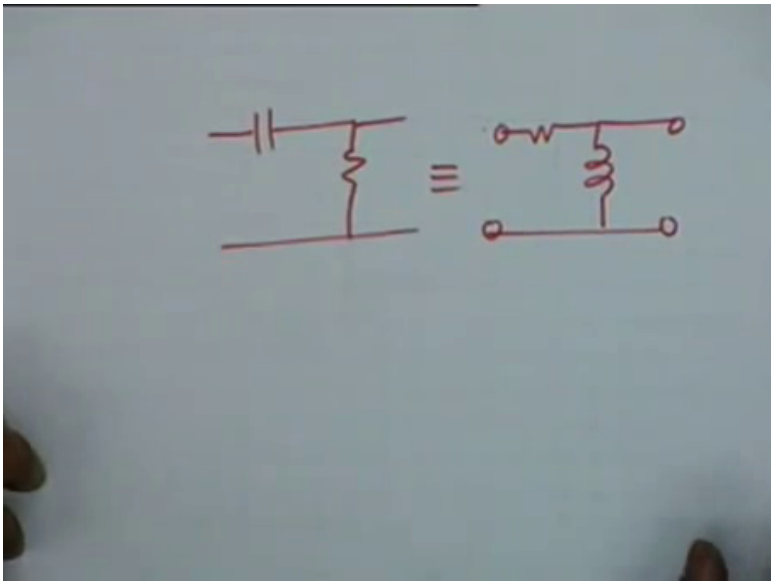

We can do that for example, here different differentiating circuit is this alright, you can use R and L, this is equivalent to this, this performs the function of a differentiator and you can show this very easily. Similarly if we use series L and shunt R, this will act as an integrator and this will be

left to you as an exercise. Now we talk about Natural response of a circuit alright. Your behavior in the hostel is natural response, when you are not when you are not monitored by your hostel superintendent it will be a natural response. On the other hand, your behavior in the example is the forced response alright and if you are in between the exam hall and the hostel, it will be combination of both because you are afraid that somebody is watching you.

Similarly for circuits, given circuit or a system when excited by voltage sources or current sources, it behaves it behaves in a manner which reflects the nature of the input and therefore that response is quite forced response alright. For example, to a rectifying circuit to a half wave rectifier if you apply a sinusoidal wave then you get half rectified sines alright half of the positive half sine, if you apply DC what will happen? It will be the DC itself alright, the capacity rectifier or the diode will always conduct and you shall get DC at the output as you saw in the Odd circuit that we demonstrated.

So, on the other hand if there are no excitations if there are no excitations from outside the circuit is left to itself then it will behave in a manner which is called its natural response. Now obviously if you have a resistive circuit, a circuit which contains only resistances, no outside interference no outside source alright, its response shall be identically equal to 0 everywhere in the circuit potential or current why? Because this circuit cannot have any initial energy, it cannot store energy, unless there is energy how can there be any response?

Similarly, you have inductance, capacitance, resistance, which is no initial energy, none of the inductors have an initial energy, none of the capacitors have so charged, none of the inductors have stored flux, some of the capacitors have stored charge, then left to itself it shall be completely relaxed, in other words all currents and voltages shall be 0. On the other hand, suppose you have a capacitance capacitive resistance circuit a CR circuit, you know the capacitor has a certain charge alright, then left itself this charge shall decay in a manner which is characteristic on the nature of the circuit, which is in the nature of the circuit and therefore such response is called a Natural response.

In general situation you might apply voltage or current to a circuit, one of the things that you must understand is natural response determining natural response makes sense only when the circuit have one or more energy storage elements alright. That is these are 2 different kinds,

inductor and capacitor, so natural response for resistive circuit is identically 0, it does not make sense to find natural response but if you have at least one energy storage element then natural response means something and you have to determine the natural response alright.

In the general case case you may have a circuit which has some initial energy and then some voltage sources and current forces are applied to the circuit and therefore the total response of the circuit shall be a combination of forced response and natural response alright, and the sum of the 2 should be the complete response of the circuit. There are 2 other terms which are used in this context, this is called one of them is called transient response and the other is called steady-state response.

Steady-state response of a circuit is the response that occurs after a long time has passed that is all the initial energies has had time to distribute or to decay, the force response has the time to establish itself firmly alright then you say it is the steady-state response and theoretically it happens when T equal to infinity. After you make the circuit after you excite a circuit and leave it for infinite amount of time, if you observe the response later after infinity then you see what you see is steady-state response. And what happens between the instant of applications of the energy sources and attainment of steady-state is the transient response it is like (())(39:21) alright.

The (())(39:23) before a person attains the manner, he runs after money he does this he does that he is in the rat race and so on, this is all transient response alright, for a circuit this is true till it reaches steady-state what behavior it shows is called the Transient response. There is a common term which says among people we learn circuit at the first instant to equate natural response to transient response and steady-state response to 1st response, these are not necessarily the same alright, these are 4 different terms; natural response, forced response, transient response and steady-state response these are 4 different terms.

Natural response may or may not be the transient response, the steady-state response may or may not be the forced response they are not necessarily the same, under certain conditions they may be the same but not in general alright. Now in finding natural response of a circuit, the 1st thing to determine is the order of the circuit that is how many independent energy storage elements are there in the circuit, if it is a purely resistive circuit the number of independent energy storing elements is 0 and therefore it is called a 0th order system. If the circuit is a differentiating circuit

for example, 1 capacitor 1 resistor or 1 inductor 1 resistor then there is only one energy storage element and it is called a first-order circuit. The term order the objective order has another connotation which will come to in a minute.

Now suppose a circuit has 2 capacitors and let us say 5 resistors, now with the order of the circuit be necessarily equal to 2, no because the capacitors may be trivially connected for example, if 2 capacitors are in serious then you know the behaves like a single capacitor, a value C 1, C 2 over C 1 + C 2. Similarly, if there are 2 capacitors in parallel then the behaviour is single capacitor of value C 1 + C 2, so you must be careful the number of energy storage elements does not determine the total number of energy storage elements in a circuit does not determine the order of the system. What determines the order of the system is the total number of mark the word "independent". If there are 2 capacitors which are not trivially connected then the circuit shall have an order 2 alright for example, let us take a couple of examples.

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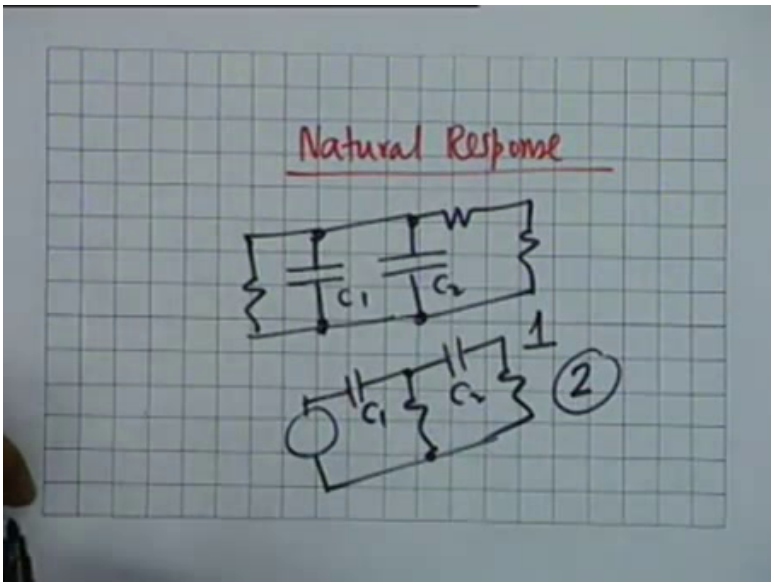

Suppose we have a circuit like this there are 2 capacitors C 1 and C 2, a resistance here then a resistance here and a resistance here. The order of the circuit is 1 because C 1 and C 2 are in parallel, they behave like a single capacitor, number of resistors does not affect the order of the system alright number of resistors do not contribute to the order of system, it is the total number of independent energy storage elements. On the other hand, if I have a circuit like this alright, these 2 capacitors C 1 and C 2 cannot be combined with each other in any manner because there

is a resistance connected here therefore the order of this circuit is 2 alright, so one thing that you learned is that the number of independent energy storage elements in a circuit independent mind you that is not trivially connected determines the order of the circuit.

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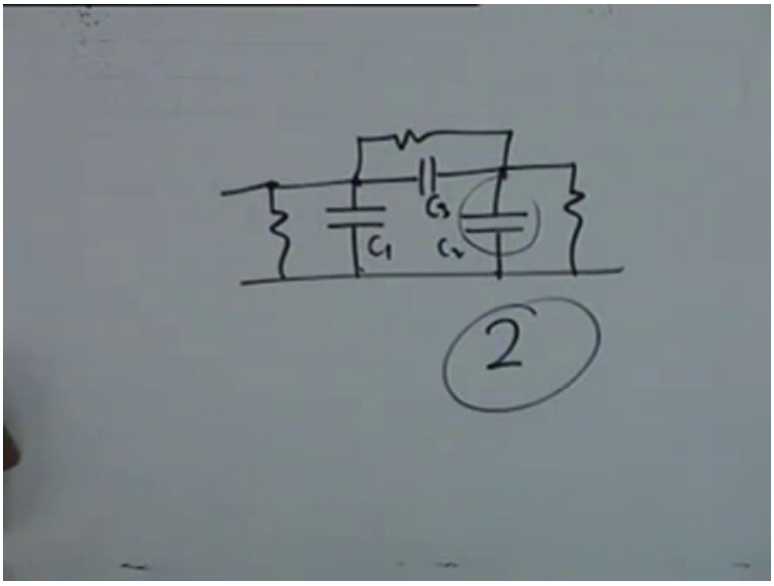

Let us take another example, suppose we have 3 capacitors in a loop like this and let us say this is the circuit; C 1, C 2 and C 3. Are these capacitors independent of each other? Obviously they are not trivially connected, you cannot combine C 1 and C 2 or C 2 with C 3 right, they are neither connected in series nor in parallel they are not trivially connected but are they independent? Can you be able to answer this question?

"Professor–student conversation starts"

Student: No.

Professor: Pardon me, they are not independent since I am asking this question perhaps the answer is no, is not it? That cannot that cannot be the logic, you must give logic.

Student: (())(44:20)

Professor: Say it again say it loud what are you afraid of?

Student: Potential of C1, C2 determines the potential (())(44:30)

Professor: That is correct.

“Professor–student conversation ends”

You see KVL is true KVL is valid therefore the potential difference of C 1, potential difference of C 3 and potential difference of C 2 cannot be independently specified, so the voltage across C 2 for example, if you specify V c1 and V c3, v c2 is automatically specified and therefore they are not independent of each other and the order of this circuit shall be 2 because only 2 capacitor voltages can be independently specified. We will not go deeper into this uncomfortable question, a bit later but for the time being for the time being let us be happy with the with identification of order of circuit as the total number of independent energy storage elements.

Now, is it necessary that all the energy storage elements should be capacitors only? No, one could have a combination of inductor and a capacitor alright. You could have 2 inductors and 1 capacitor and still the order could be 2, is that possible?

Yes.

Yes because inductors could be trivially connected, alright. Now how is it that the natural response natural response of a circuit is determined by energy storage elements and not by resistors? This statement has to be taken as a (())(46:09) alright. Suppose you have a capacitor isolated capacitor you charge to a voltage V 0 and leave it undisturbed leave it alone, well it will then lose charge, its natural response will be V 0 whatever V 0 you have set it will be 0, whereas such things are completely boring to an engineer. If a single voltage or current does not decay with time or increase over variation, it does not qualifies a signal alright, except for power supply.

Power supply is necessary because we cannot you cannot operate transistor circuits and Op amp circuit without a power supply, the power supply is constant DC, you require DC there, but in all other cases what we require what we require to be able to perform a given function our voltage and current varies with time therefore, in order that the natural response become interesting to an engineer there must be a resistance somewhere right. A clearly capacitive circuit totally capacitive circuit left to itself shall conserve all the voltages that is given to it, a totally inductive

circuit shall conserve all the flux which has been generated in it and therefore we do require at least one resistance otherwise the natural response does not make sense alright.

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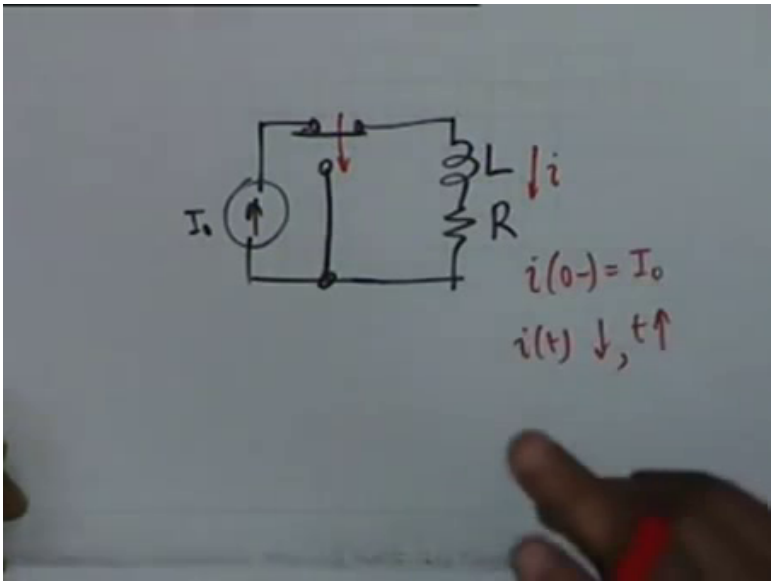

And you could have for example, an inductor in series with resistors. Well, is the equivalent circuit of a practical coil, if you wind a coil along form this is the practical circuit, you get an inductor in series with resistance. And suppose you have a switch here alright, which is originally connected here and there is a current source I 0 originally connected here. Then if sufficient time has passed, the inductor current inductor current shall be equal to I 0 alright, then at T = 0 the switch is thrown opened to this point which is connected to ground alright, at T equal to 0 the switch is thrown to the other contact then the current generated is disconnected and flux generated in the inductor due to the current I how much flux?

Student: (())(48:44)

L times I, inductance times the current. This flux now finds an easy path through this and therefore the flux gradually decreases or the current in the circuit i which is 0 – was equal to I 0, i of t shall decrease as t increases, i of t decreases as the increases and that is the natural response this is what is a filter is to us and we shall explore this point further on Friday.

Student: You said in natural response we can have a charge energy storing, one can have energy storing device in which energy stored but we cannot have external voltage...

Professor: We do not have external storage in it, initially it is charged then it (())(49:41)