Circuits for Analog System Design

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Module No. # 01

Lecture No. # 03

Some Applications of Transistors - I

Today, we spend some time on reviewing what we had done so far and work out some problem in the area that we had discussed so far, so that we can understand the subject much more deeply and also it will work as a test. So, what I do is, I will work out some problems regarding transistor applications and then I will also work out some problems using operation amplifiers, so that you will able to appreciate the subject much more deeply.

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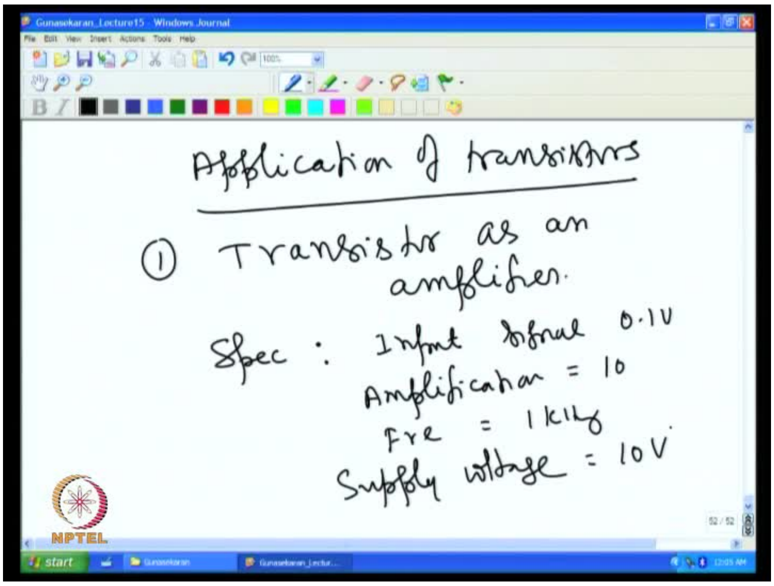

So, let us see the application of transistors first. For that, let us take transistor as an amplifier; if you want to design a transistor amplifier, how we go about doing that - transistor as an amplifier?

Now, if you want to design a transistor amplifier, then I fix the spec, so that we have the spec for the design. I want that the transistor amplifier input signal is 0.1 volt; then I want amplification by a factor of 10, amplification required is 10; assumed signal frequency is 1 kilo hertz, then supply voltage supply voltage is we have say 10 volt, it is the supply voltage that we have and then I have to have a load.

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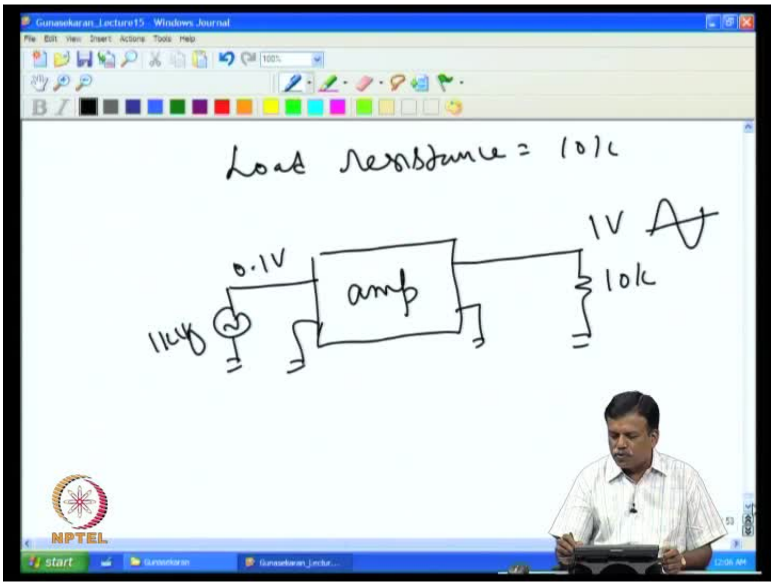

For example, what is the load that is supposed to be delivered to this amplified voltage? Load resistance just take it as 10 k; so, what we want is, we have to design amplifier using at transistor. So, I have this amplifier stage here and this input signal is given here; that is the input signal that is in 0.1 volt and then 1 kilo hertz the output is here, the output supposed to be loaded to 10 k; so 10 k I should get 1 volt a c supposed to come out, so how you go about designing this.

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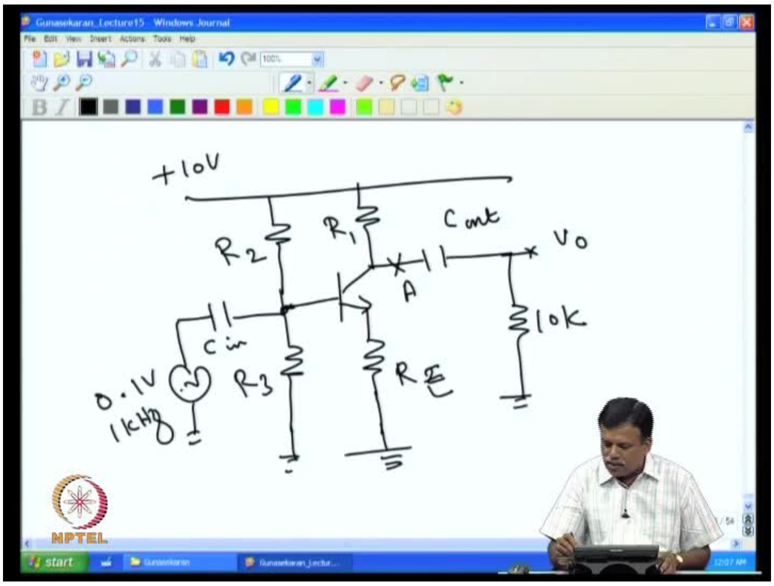

So, we if you look at the general transistor amplifier configurations, that looks like this; you have the transistor, then you have this resistance, and then the collector load resistance, and this is supply voltage plus 10 volt, and that is grounded here. Then, we have the two biasing resistances, this is load supposed to be 10 k and this is the output voltage and our input signal is applied here, this is 0.1 volt 1 kilo hertz. So, this is our next, this is the actual circuit that we will be using here.

Now, only thing is we have to decide on these resistances, resistance values say - I will take it as R 2 or I will call R E, then this is I will put it as R 2 then R 3 and then we have c - input capacitor and c - output capacitor here.

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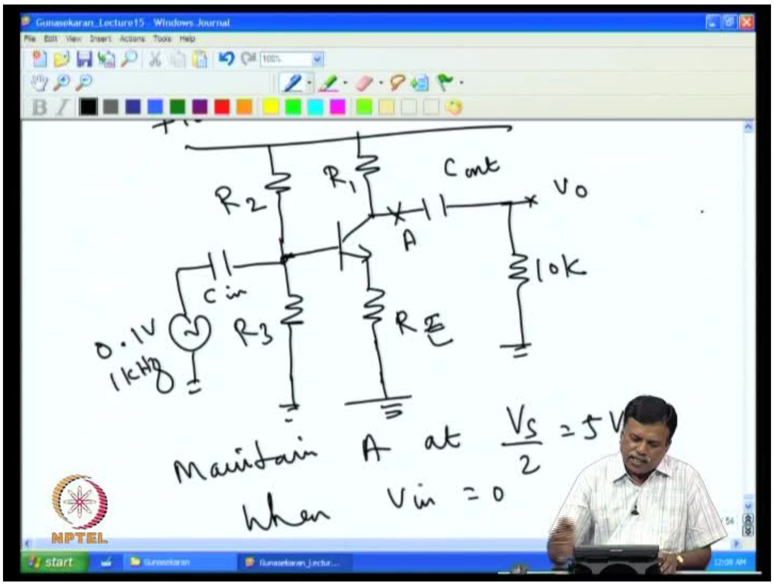

Now, in all this design, it is better to keep the operating point that is, this point at mid value of the power supply, power supply voltage is 10 volt, select this, call it as point A. So, without any signal, without any input signal keep, this point A at half the supply voltage. So, our policy would be that maintain A at V supply by 2 that is equal to 5 volt when V input is equal to 0; when there is no input voltage then make sure that the point A is at 5 volt that is the first step that we have to keep it.

Now, to make get that one, we have selected this R 1 and R E, R 2, R 3 values. Now, first what we have to do is, you know this 10 k acting as a load, when there is when we are applying a ac voltage here, then we are getting amplified ac voltage here and that ac voltage actually flows through this (Refer Slide Time: 04:53). So, this is acting as a load when current is flowing through that current actually comes through that, effectively this R 1 is getting loaded by this load, that is this 10 k. We have to make sure that R 1 is much smaller than this 10 k then only the loading effect can be minimized. Normally, factor of 10 is taken in consideration to neglect the loading effect that means, if this is 10 k then obviously this loading effect not to be seen, it means, R 1 should be 1 k.

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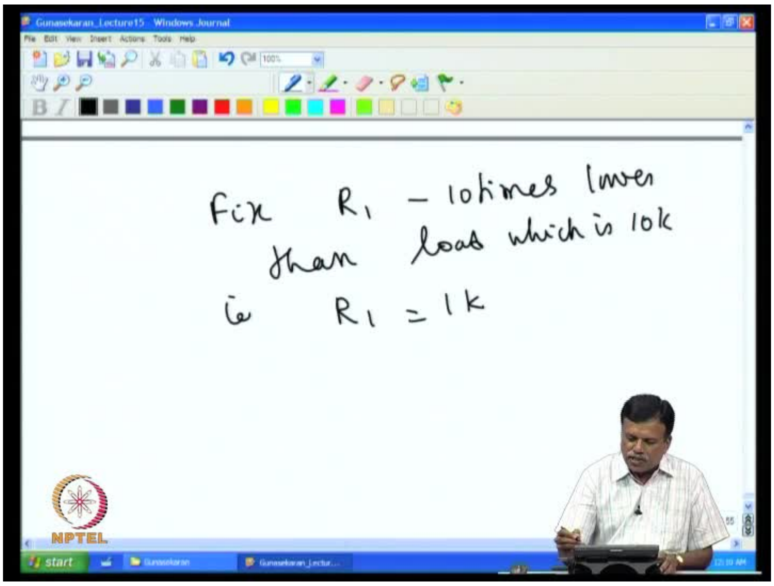

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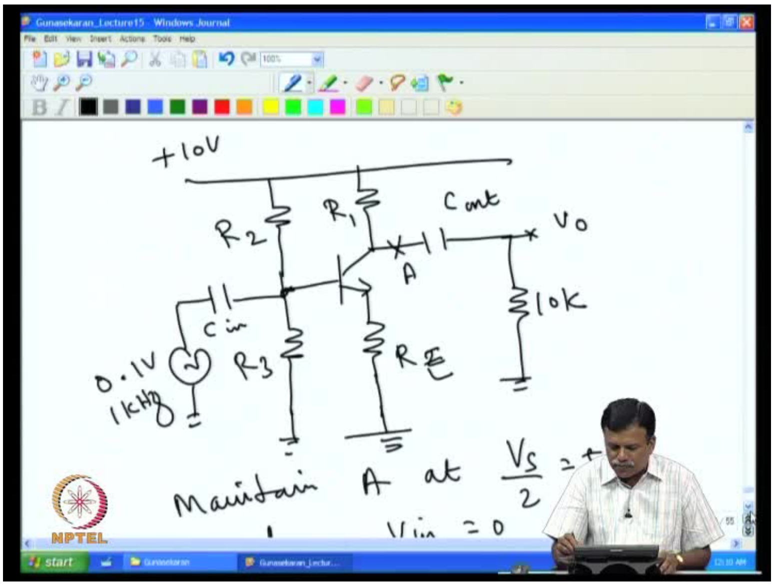

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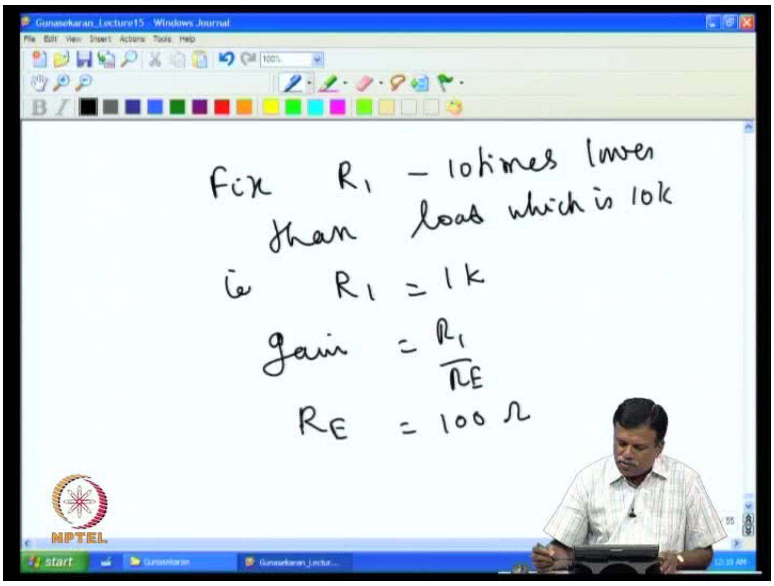

Our first step would be, consider the load and then fix R 1 - 10 times lower than load which is 10 k, that is, in this case R 1 supposed to be 1 k, I will fix R 1 as 1 k. Once, R 1 is fixed than easy to fix R E, because the gain is actually given by the ratio between these two; gain is ratio between R 1 and R E, the R 1 and R E ratio is the gain. Since, R 1 is fixed, R E can be fixed, so gain is actually R 1 by R E; so, R 1 is 10 k, R E automatically comes to be 100 ohms then R E is fixed R 1 is fixed.

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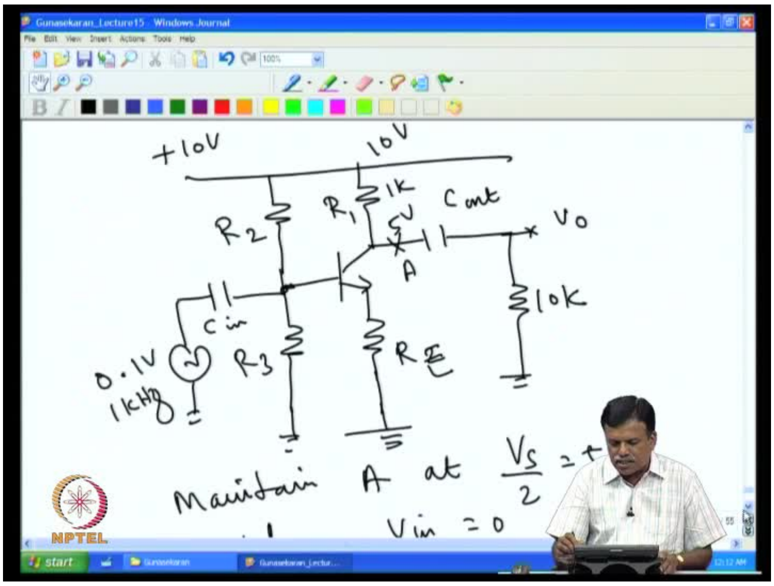

If this is a case, then now we have to fix the other two resistors that is - R 2 and R 3; that is R 2, R 3 this is two bias resistors, that is, these two bias resistors to be fixed.

We know this is 100 ohms then we had find out what will be the voltage at the emitter. Now, midpoint we had taken that, this is at 5 volts because A is taken as 5 volt that is what our starting point; so, if this is 5 volt when there is no ac here, there is 5 volt that means voltage across the R 1 is 5 volt that this is 10 and this is 5. If I look at this, this point is at 5 volt, this is at 10 volt, so voltage across R 1 is 5 volt, current through this resistance is 2 k; so, current through this is 5 milliampere, current through this R E is almost 5 milliampere because neglecting the base current effect. Then, if this 5 milliampere current is going through this, the next step is finding the current through R E.

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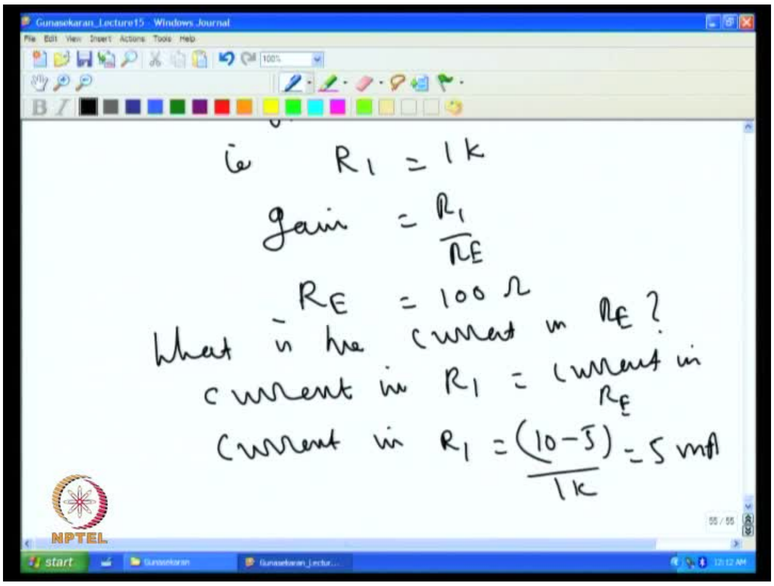

What is the current through R E? That is the question; so, current in R 1 is equal to current in R E; so, current in R 1 is equal to R 1, it is actually 10 minus 5 divided by 1 k that is 5 milliamps.

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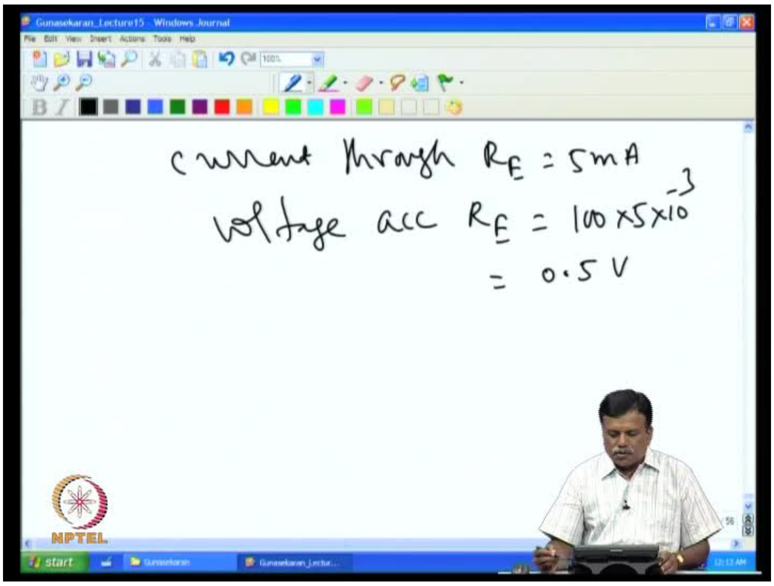

Current through R 1 is 5 milliampere, current through R E also 5 milliampere; so, current through R E is equal to 5 milliamps and current in R E is known; so, we can always find voltage across R E, voltage across R E comes 100 ohms into 5 milliamps that is 0.5 volt.

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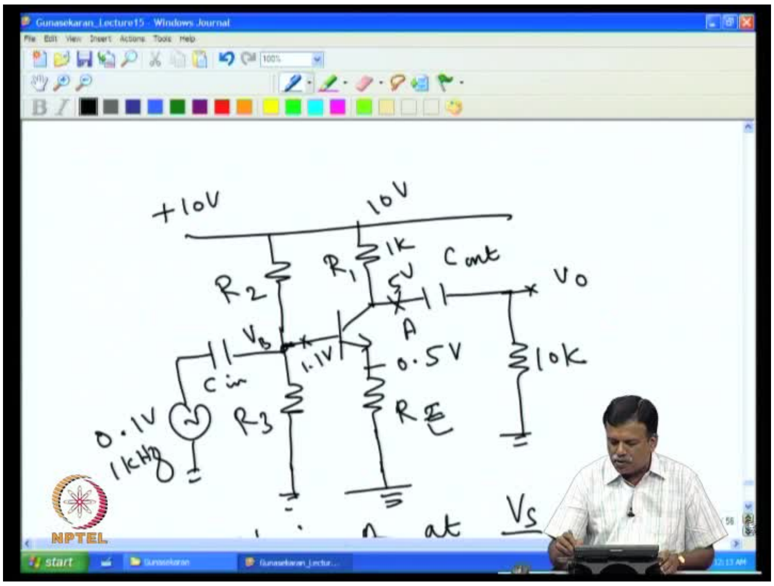

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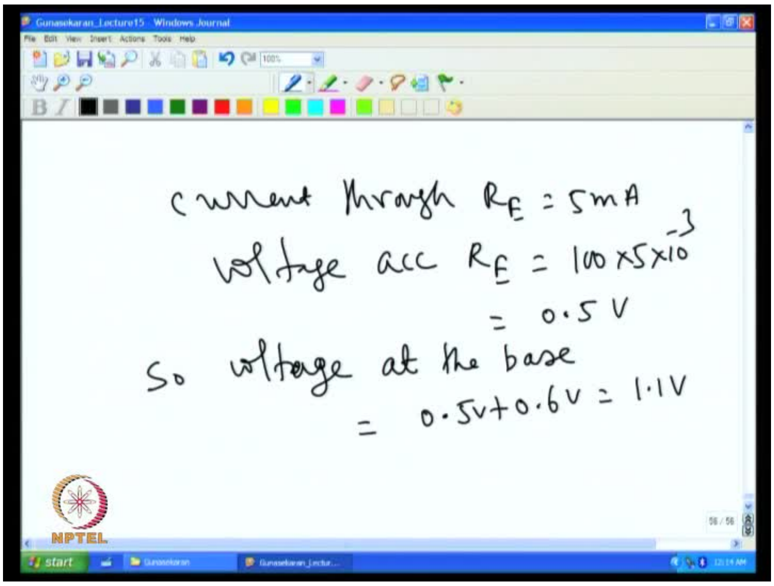

The voltage at R E is 5 milliampere, if I go back to the circuit and see what have we got? That is voltage at this point, it is becoming 0.5 volt when there is no ac signal voltage at this point, it is 0.5 volt is coming, then we know that if this is 0.5 and this supposed to be sitting at 1.1 volt, we call this as VB voltage at the base is 1.1 volt. We can write that, it is actually brings that voltage at the base to 1.1 volt.

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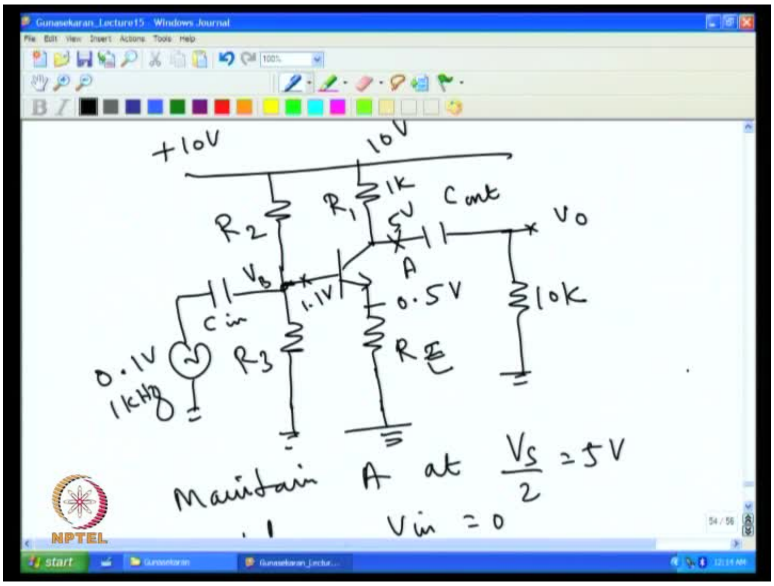

Voltage at the base of the transistor base is equal to 0.5 plus 0.6 volt that is equal to 1.1 volt. We arrived at the base voltage then we had also find out what will be the base current because we had, now fix other R 1 and R 2, now we know the voltage at base, now I should know what is the base current, because our idea is this current whatever is flowing through this, the current that is flowing through this much more, than the base current to neglect the effect of the base current, otherwise we have to iteratively calculate that is not required; so, we can find what is the base current.

We know the current through this is 5 milliampere, because we had taken this voltage at 0.5 volt that means, 5 milliampere current was flowing through this 5 milliampere current, it is flowing through this (Refer Slide Time: 11:26). If 5 milliampere is the emitter current, then base current will be 5 milliampere divided by h f e that is taken as 100 as h f e for the transistor, then we can calculate the base current.

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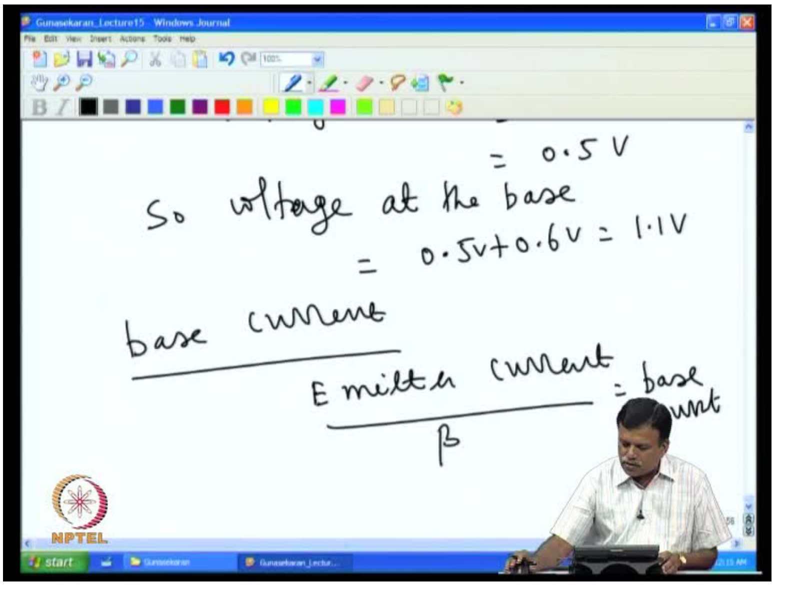

Next, we calculate the base current; so, base current calculation, we have to do, that can be done like this. So, I would find the base current, emitter current is known, emitter current divided by beta of the transistor is equal to the base current.

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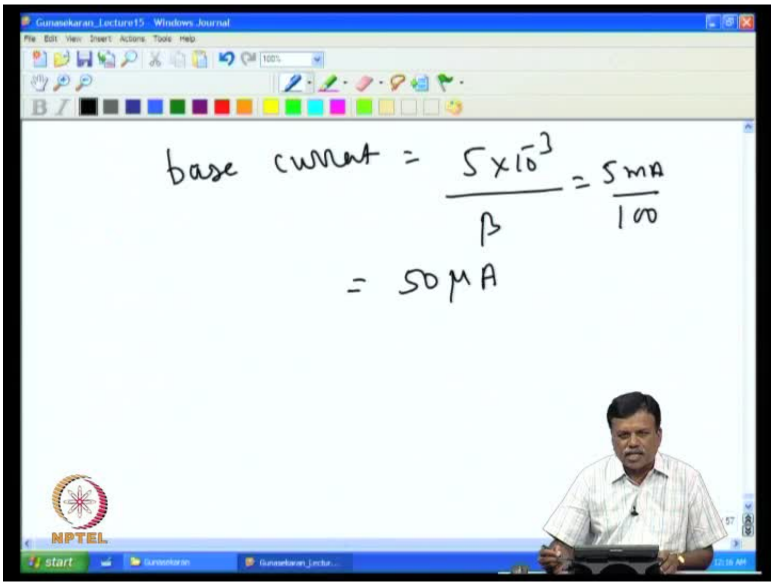

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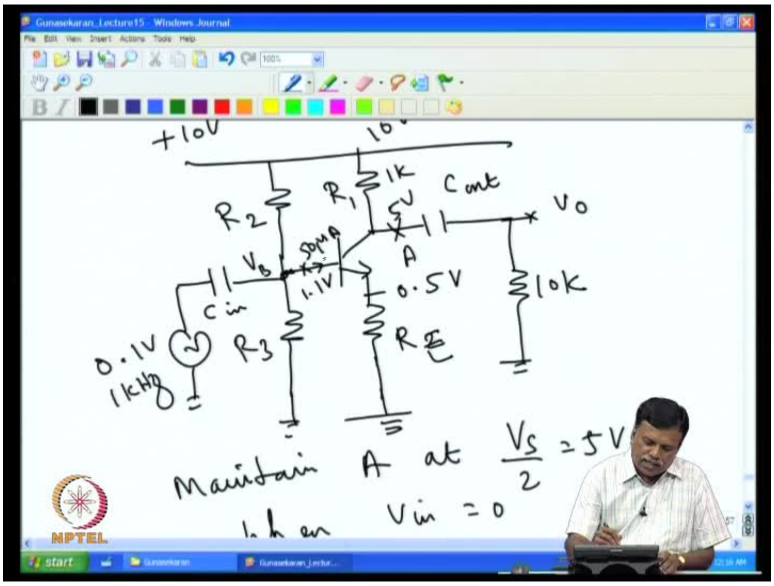

Base current comes out to be, base current would be 5 milliampere divided by h f e that is beta, it is actually equal to 5 milliampere divided by 100 that comes out to be 50 microampere, we got the base current. Once base current is known, I can desire on the other current through this R 2 and R 3. So, the base current is now taken as 50 micro amps that are the current is flowing here; this current should be smaller compared to this means I keep this current as 500 microampere. So, current through R 2, R 3 need to be 500 microampere.

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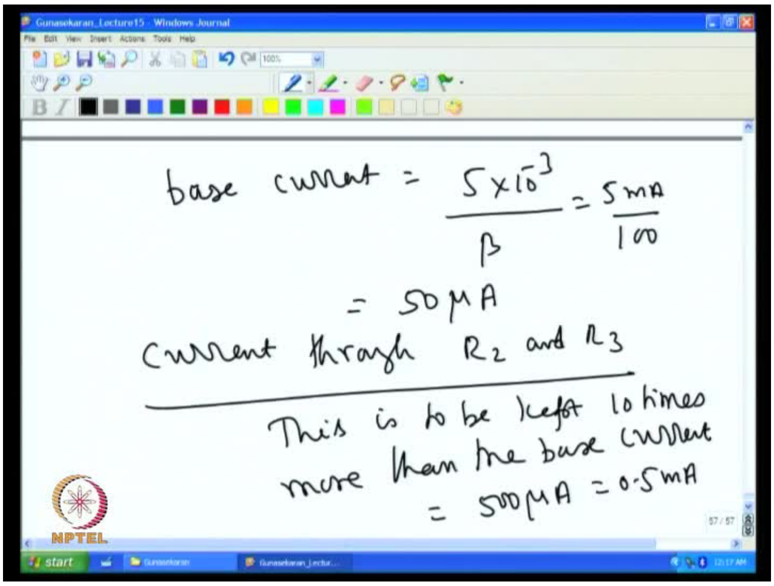

So I make current through now I find out current through the R 2 and R 3; this is what we decided this is to be kept 10 times more than the base current. We kept 10 times base current; actually it can be kept as 500 microamps or equal to 0.5 milliamps.

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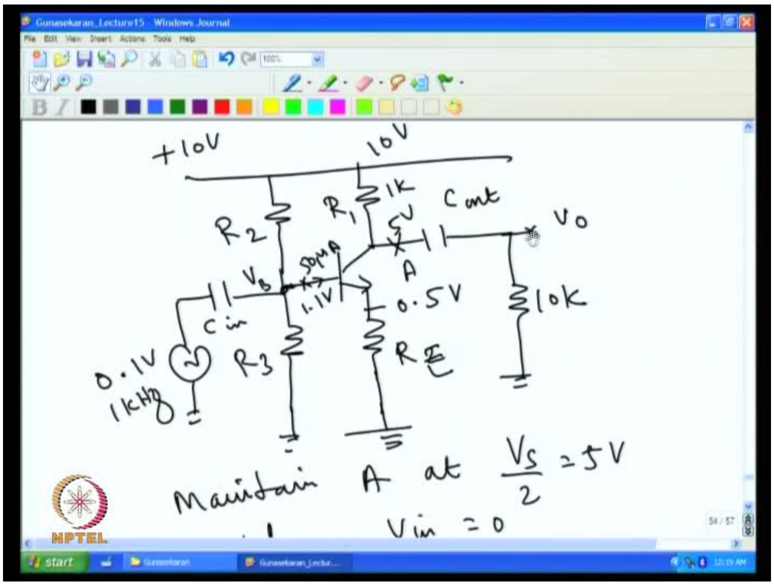

Now, we are very close to our design because we got the R 2, R 3 current and then voltage across R 3, that is, if you see the circuit, the voltage across R 3 is 1.1 volt and we know the current through this is 500 micro amps, then we can find out the value of R 3. Once, the value of R 3 is known, R 2 can be computed because we know the voltage across R 2 that is 1.1, if this is 10 then we know roughly 8.9 volt is what is there and current through this is 0.5 milliampere; so, we can desire on R 2.

For example, if we take this 1.1 divided by 0.5 milliampere, roughly 2.2 k is coming here and then this is roughly 9 volt and then 9 volt divided by 0.5 milliampere gives us 18 k for R 2.

So, 18 k and 2.2 k will give 1.1 volt here and this amplifier will nicely amplify this voltage, that is, this input voltage by effect of 10 and amplified voltage that is 0.5 volt will be appearing across v o, it is 180 degree phase reversal.

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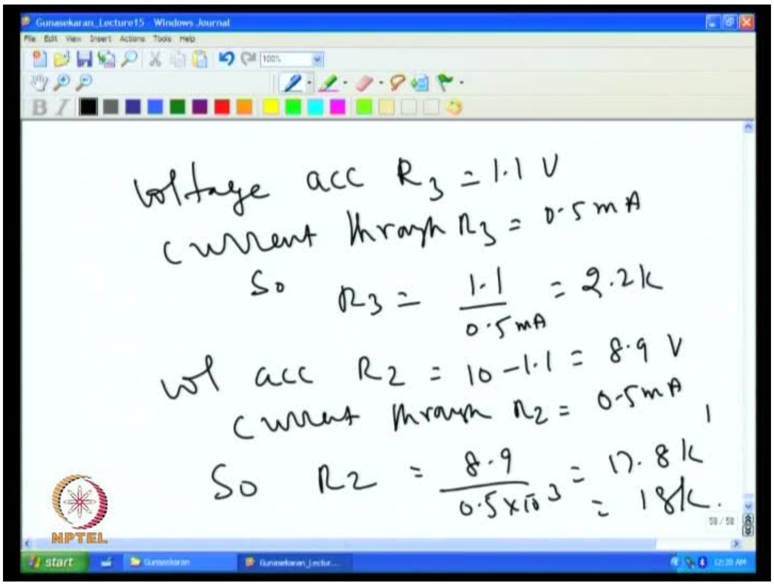

Now, we can complete the design, voltage across R 3 is 1.1 volt and the current through R 3 is 0.5 milliamps, so R 3 actually comes 1.1 divided by 0.5 that is, 2 point milliamps that equal to 2.2 k. Similarly, voltage across R 2 is actually 10 minus 1.1 that is 8.9 volt and the current through R 2 is again 0.5 milliampere. So, R 2 comes 8.9 divided by 0.5 milliamps that comes 17.8 k; so, 18 k would be fine. So, that is how the design goes.

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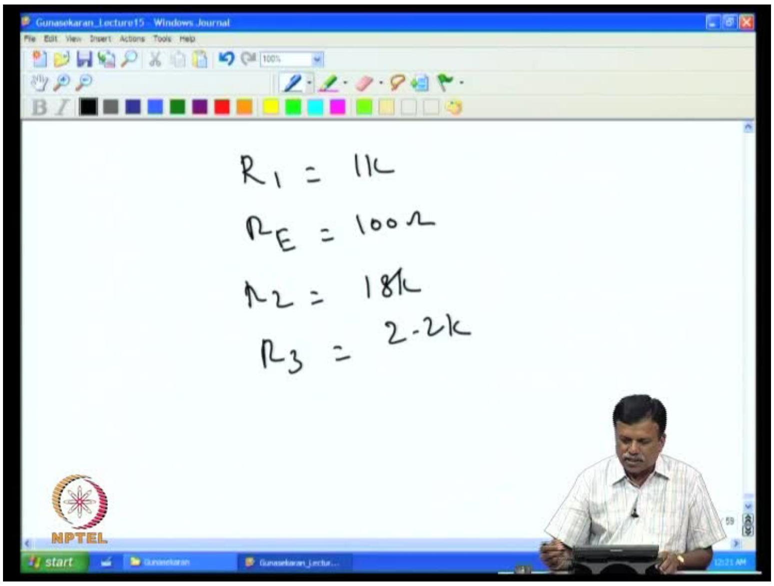

If you look at the values, we will get R 1 is actually 1 k, then R E comes as 100 ohms, then R 2 coming as 18 k and then R 3 is coming as 2.2 k that is how this amplifier is designed.

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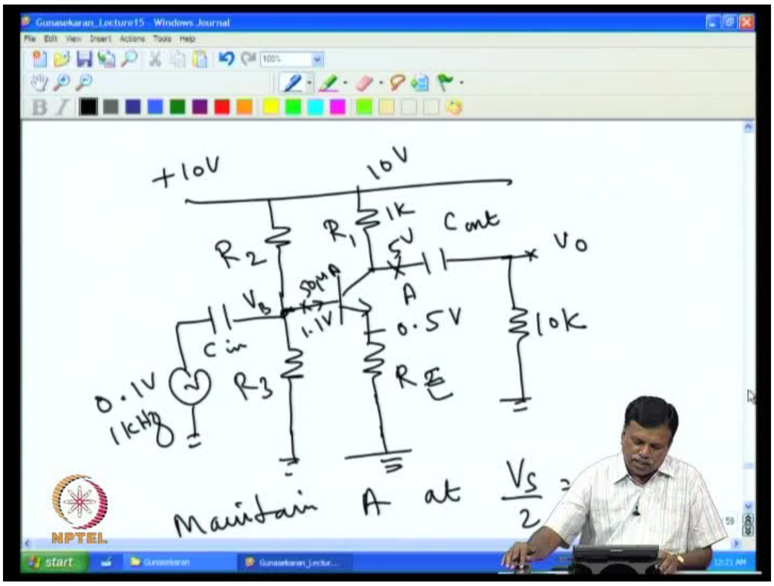

One can work out in the same line depending upon the supply voltage and the signal level and so on. One can always find to the same design, but one should be careful that when the voltage at the collector; if we for example, in this case, this amplifier works alright up to some point beyond which that it does not work. The limitation is that, if I increase this by per say increase this voltage to 1 volt then I except to get here 5 volt, 10 times amplified that it will be 10 volt amplified voltage supposed to come and that cannot happen because supply itself 10 and what we have kept is only 5 volts as the operating point here.

So, this works at 0.1 volt and it gives you here 0.5; if I give here 0.2 then I will get 1 volt then trying to go beyond that, then you will have problem because may be I will get the point here 2 volts swing or 3 volts swing, maximum I can except not beyond that; so, you can go at the maximum 0.3 volt here, at the maximum in this design.

One can get different values of R 1, R E, R 2, R 3, depending upon this supply voltage and the input voltage level at excepted, and of course, the load also place a dominant role, then only thing is that capacitor to be selected for c in and c out. The impedance of c 1 and c 2 must be small compared to the loads that they are seeing this capacitor c, seeing this R 2, R 3; if I take R 2, R 3 as a load resistance, so impedance of this c in should be much smaller at 1 kilo hertz frequency compared to R 2, R 3. Similarly, impedance given by this must be much smaller compared to the load resistance so that not much voltage is lost; so, we have to decide on c in and c out.

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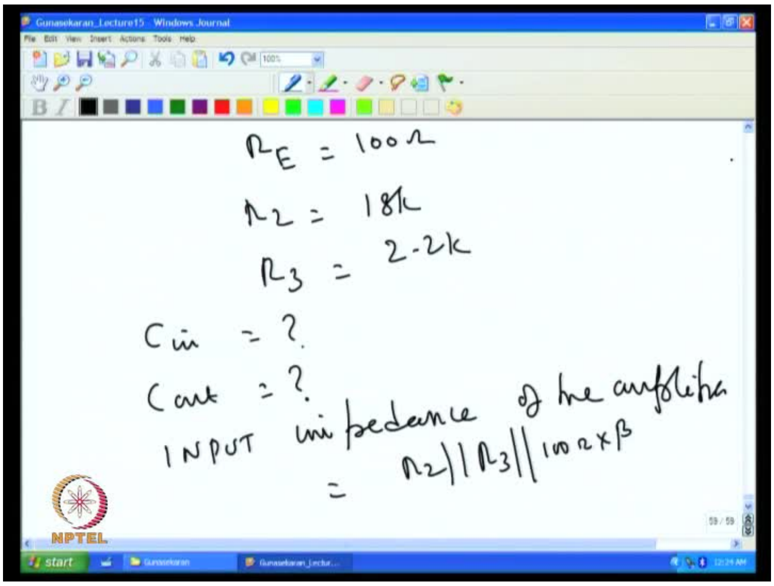

How to decide on the c in and c out? We have to find c in what is the value and c out what is the value? So for, this is to find what is the input impedance? The input impedance is impedance of the amplifier, actually it is kind of R 2 parallel R 3, then actually you have parallel 100 ohm into parallel 100 ohm multiply by beta that is also coming in, because when if you look at the amplifier I will redraw the amplifier here.

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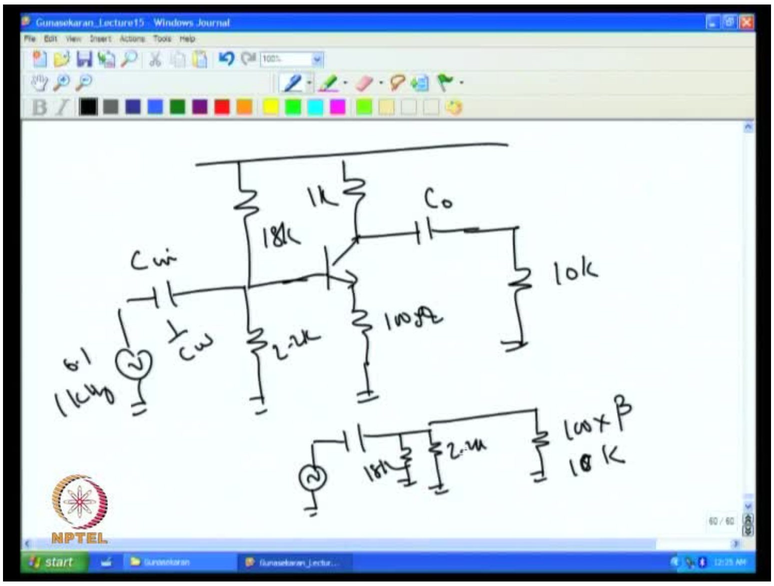

If we look at the amplifier again, here 1 k and then this is taken as 18 k, and this is taken as a 2.2 k, this 100 ohms, and then we have to find this c out, and this is 10 k, this c in, this is 1 kilo hertz 0.1 that is impedance - that is 1 by c omega should be much smaller compared to parallel combination of these two, and the reflected resistance of this emitter appears here. If I draw the input impedance that is nothing but parallel combination of this, this (Refer Slide Time: 21:02) and then reflected resistance of this 100 ohm.

Reflected resistance of the 100 ohm is, 100 into h f e. The input looks like this, the input circuit look likes this, so you have this source with this impedance, then you have this 2.2 k parallel 18 k eighteen k and then parallel this 100 into beta that is - actually 10 k.

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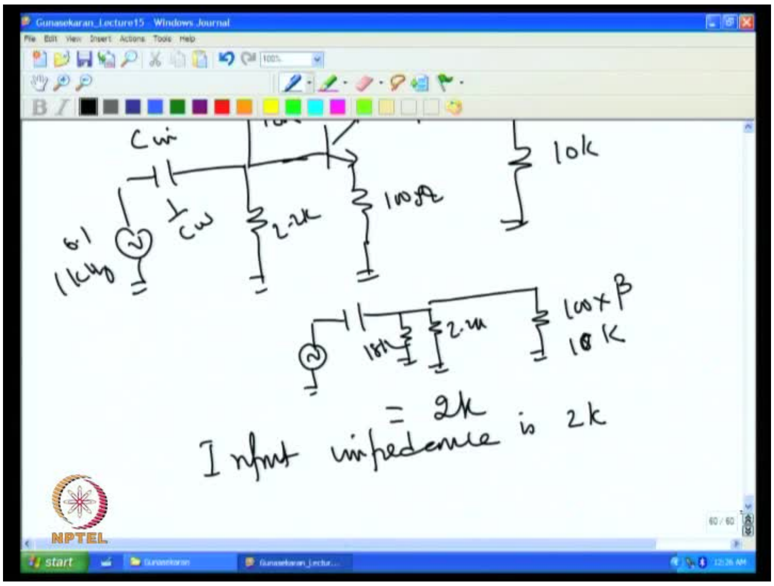

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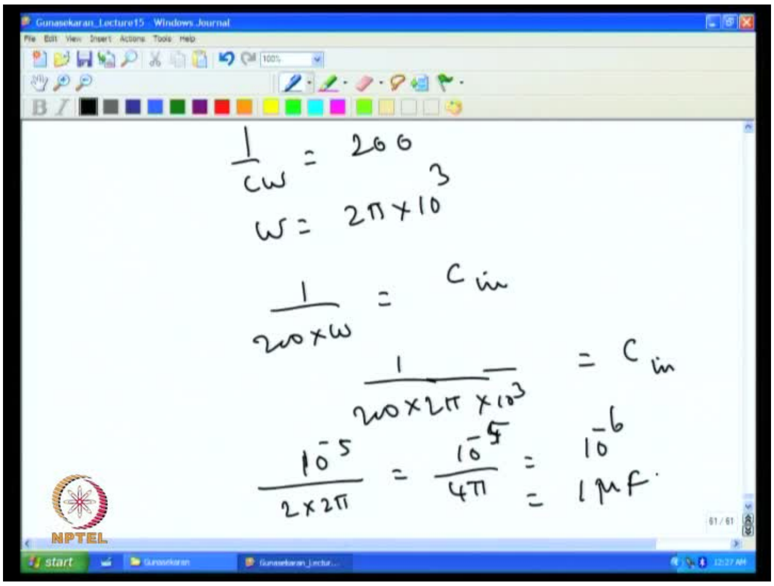

In this case, if you see this 2.2 k is dominant, because if we take 10 k and 18 k that is much higher than this 2.2 k. One can take roughly 2 k as the impedance of the input, impedance of the source, we take this is equivalent to 2 k so input impedance is 2 k. The capacitor should have much lower impedance than 2 k, so 10 times lower, I can take 1 by c omega should be 200 ohms 10 times lower. I had taken the omega is actually 2 pi into 10 power 3, 2 pi f at 1 kilo hertz.

One can find c, so you will get 1 by 200 into omega that comes as c; so, you will get 1 by 200 into 2 pi into 10 power 3 comes as the c input rather; so, if I take this one that actually comes 1 by 10 power minus 5, this 3 plus 2 pi gone, so you have 2 into 2 pi it will be here, so that will be 10 power minus 5 divided by 4 pi roughly 12 it comes. So, you need this is 10 to the power minus 5 it will minus 5 by 4 pi; so, that will be 10 power minus 6 roughly farad, that is, 1 micro farad is required for c in.

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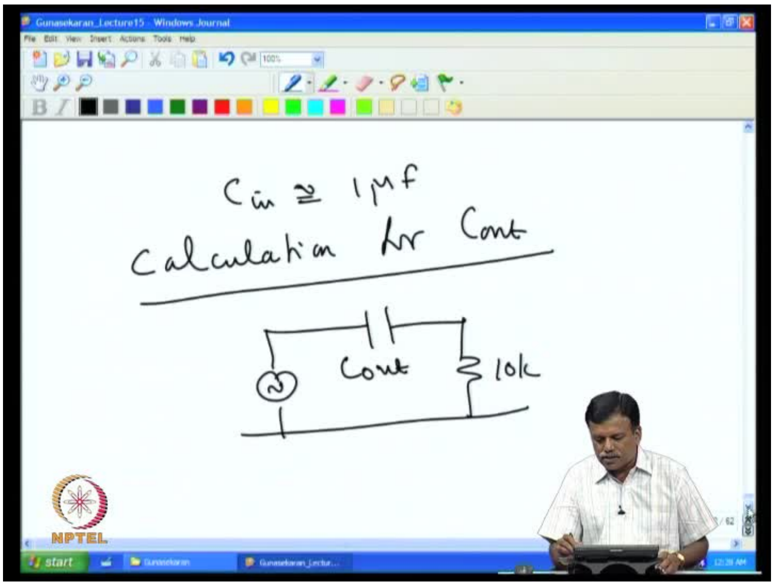

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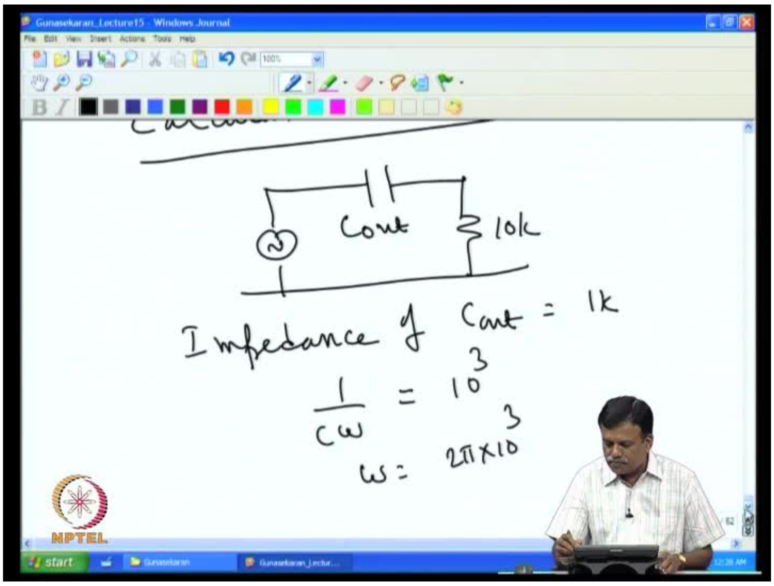

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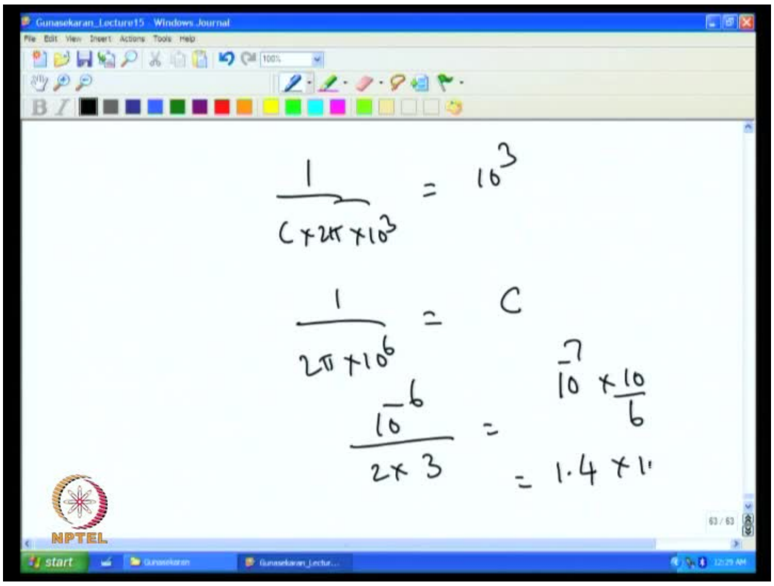

So, you need we had decide c in as nearly, 1 micro farad it is what is required. Similarly, we have to calculate for c out. The equivalent circuitry that you have the output voltage passing through this resistance c out and going to 10 k that is - c out. So, c out should be much smaller than 10 k, so roughly c out supposed to come 10 times lower, so I will put it as 1 k. The impedance of the c out would be 1 k, supposed to be 1 k so that 1 by c omega comes to be roughly 10 power 3, we will get; omega is as usual at 2 pi into 10 power 3.

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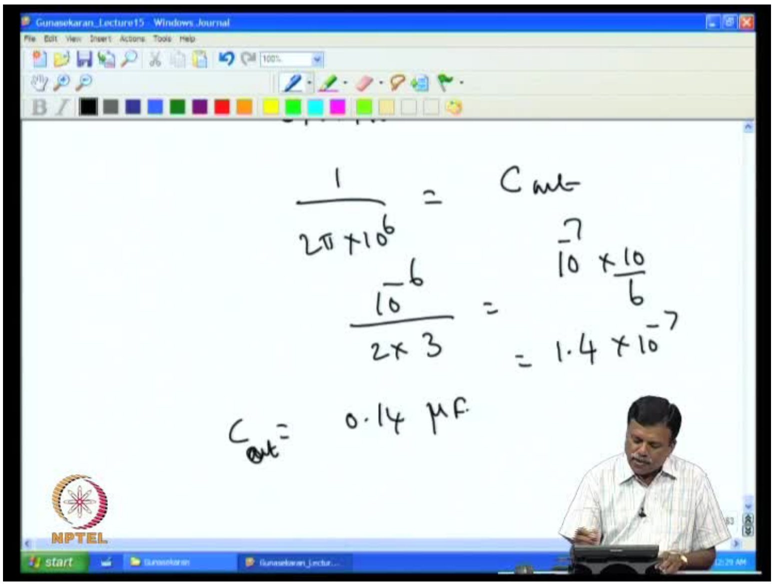

You will end up, 1 by c into 2 pi into 2 power 3 is equal to 10 power 3; so, you will have 1 by 2 pi into 10 power 6 as c coming in so that actually comes out to be 10 power minus 6 divided by 2 into roughly 3; so, 10 power minus 7 into 10 by 6 that is 1.4 into 10 power minus 7, which actually turns out to be. So, the c value comes out be c out rather, c out comes to be 0.14 micro farad.

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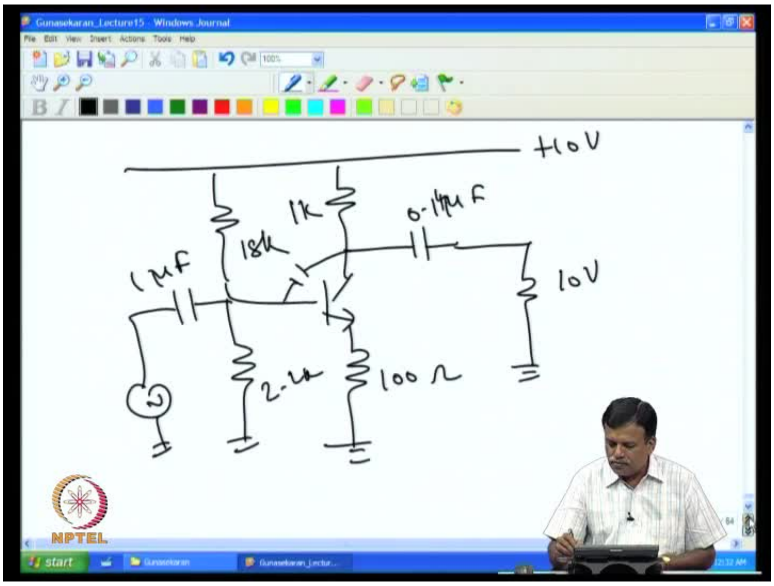

We are now arrived at all the values for the circuit. If you look at the amplifier design now, it look like this you have this a connected here at 100 ohms, then here we have put 1 k, then here we have put 0.14 micro farad, then you have the load resistance of 10 k, this is given a plus 10 volt, that is ground. We had these two resistances, this is 18 k and these is 2.2 k and then we have this and apply the voltage here, and this is put as 1 micro farad that is - how the circuit design is completed.

The amplifier can be designed step by step using this procedure so that the required performance is obtained. Of course, you have not drawn the equivalent circuit of this transistor by taking care of miller effect capacitor and so on and that is not required right now at this point, because nowadays we do not design this kind of amplifiers, because we normally use operational amplifier. This is only to illustrate how the amplifier is working, we had done this exercise.

In actual case, actually we have to consider there is a capacitance across this and because of this capacitor, the output voltage partially fed back to this and then that applies the voltage here, reduce the voltage at this point, that also reduce the voltage at this point, but this capacitor effect is not significant at 1 kilo hertz, so need not to worry about that. In high frequency amplifiers they do not worry about the effect of this as well so. At this point, we are not looking at the design of high frequency amplifier, so we are not bothered about this capacitor effect.

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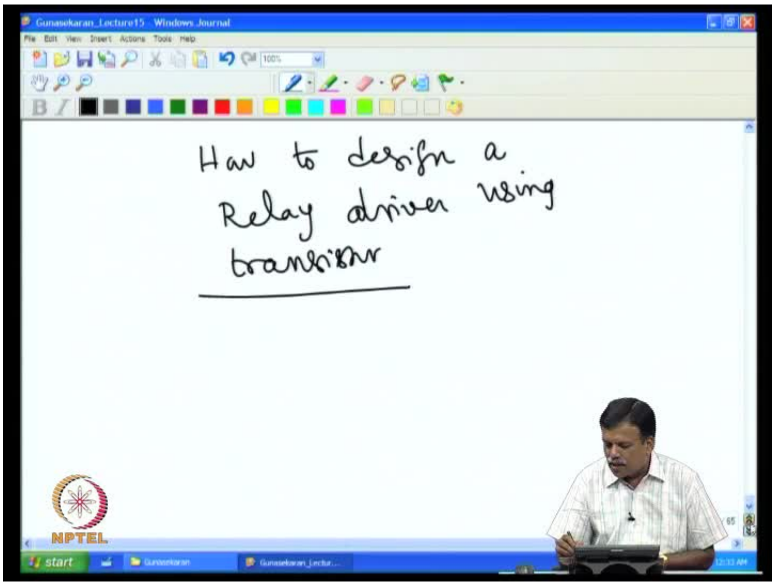

Let us see another design example namely, how to use the transistor as a switch and for switching applications, so that we can use that transistor along with probably the MOSFET at very many different places, analog circuit as a switch. For example, I want to drive a relay, driving a relay using a transistor; we look into this design at this point of time.

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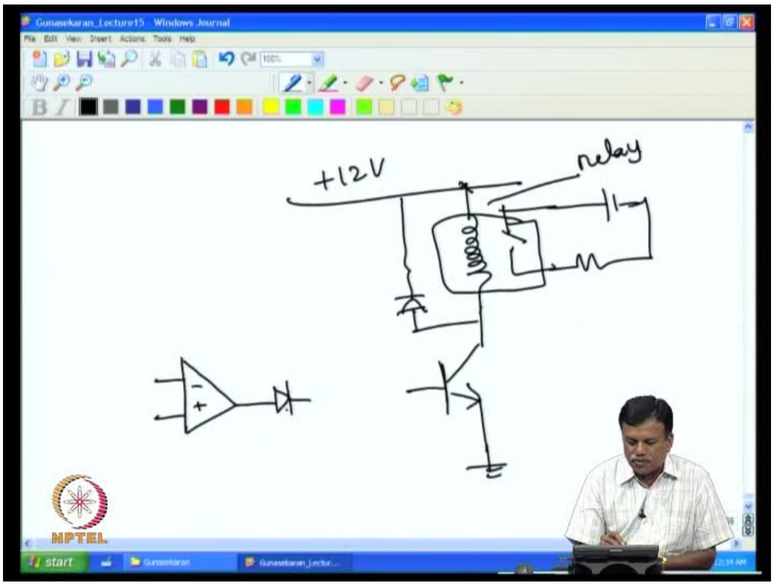

How to design a relay driver using transistor? The circuit that we are thinking is like this, we have a relay, assume this is a 12 volt relay, and I have supply of say plus 12 volt, and then this relay is such anything, but you have a coil and then it has a contact. So, when coil is energized the contact is full closed, when the coil is switched off the contact is open, so that this contact can be used to carry some load current, then I can put a load like this. Whenever the current flows through this coil, this contact will be energized and the current will be flowing through this; when you stop the current flowing through this the contact will be open and the relay will be off; so, this is the relay part actually.

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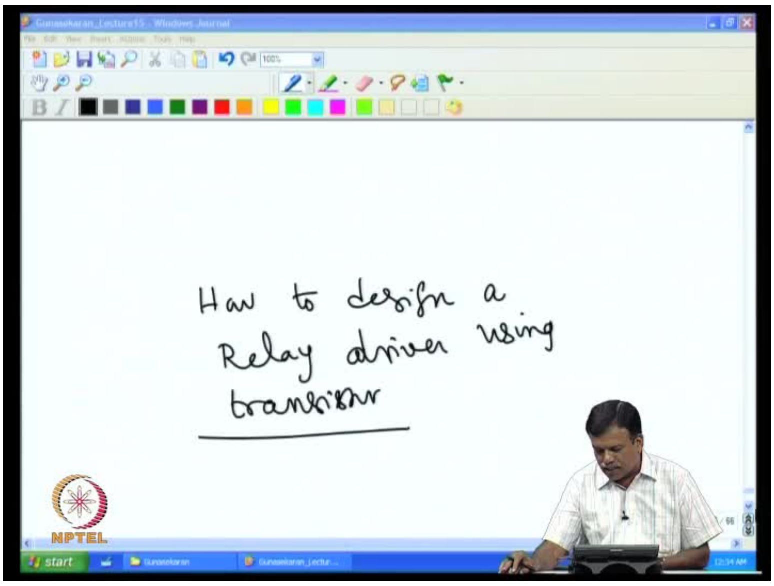

This is to be switched on and off using a transistor. So, I can use this, I can put this, then we also have this, I will explain about this use of this diode (Refer Slide Time: 29:59); without this diode the trans invariably goes bad, you put this. Then, we have a signal come in, you know the for example, another operation amplifier, assume it is there and that gives the signal is to switch on this; so, when this is high it will be plus 15, when this is low it will be minus 15; when the output is plus 15 the relay should be on, when the output is minus 15 relay should be off that is - what we are planning to do.

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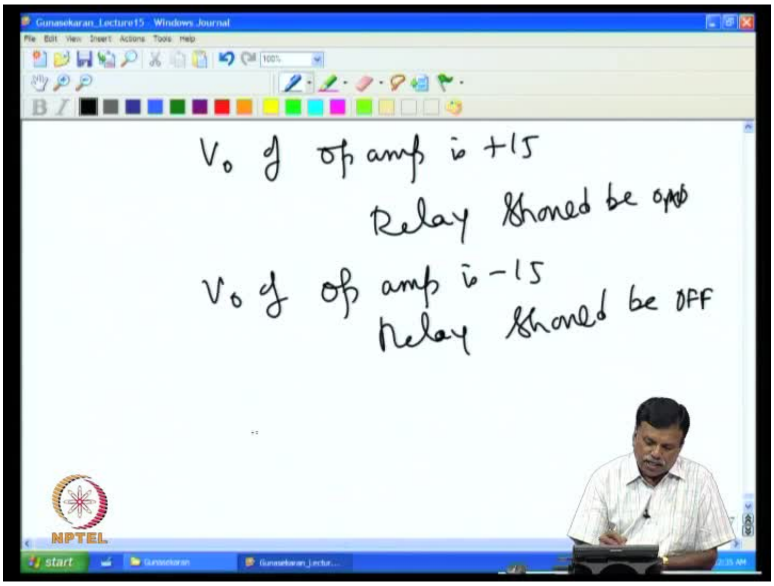

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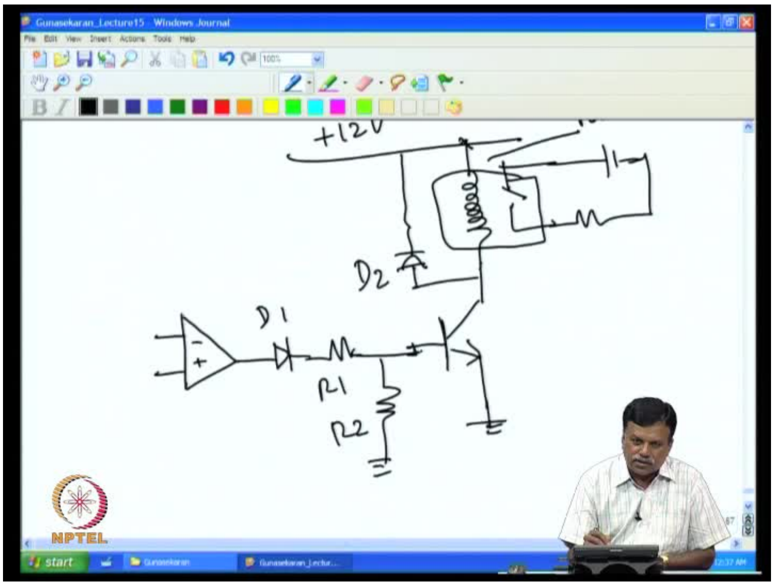

So, writing the problem statement actually what we want is, I will put a point here, I write here, it is when V output of op amp is plus 15 relay should be on, V output of op amp is minus 15 relay should be off. So, assume that we have given out that means how will you complete the circuit? I have to complete the circuit by linking the base to link this one to the base, so I put one diode plus I put one resistance here, so I call this is R 1 and this is R 2, you have two diodes D 1 and D 2.

D 1 actually, when the minus comes, it does not allow the voltage go to the base; when it plus 15 comes, it allows the voltage go on and that will switch on this. Now, one thing is we have to select, what is the value for R 1 and R 2, then we also should explore why we need D 2. Of course, without D 1 also it can work, but it is not a good design you know banking minus on the transistor and if it is in the transistor, base emitter voltage x is 7 volt, most of the transistor actually goes bad with the current is not limited. Of course, you have the current limiting resistance here, it may not go bad but nevertheless, it is not necessary to design like that, it is consider as a bad design banking minus and the transistor which is not required.

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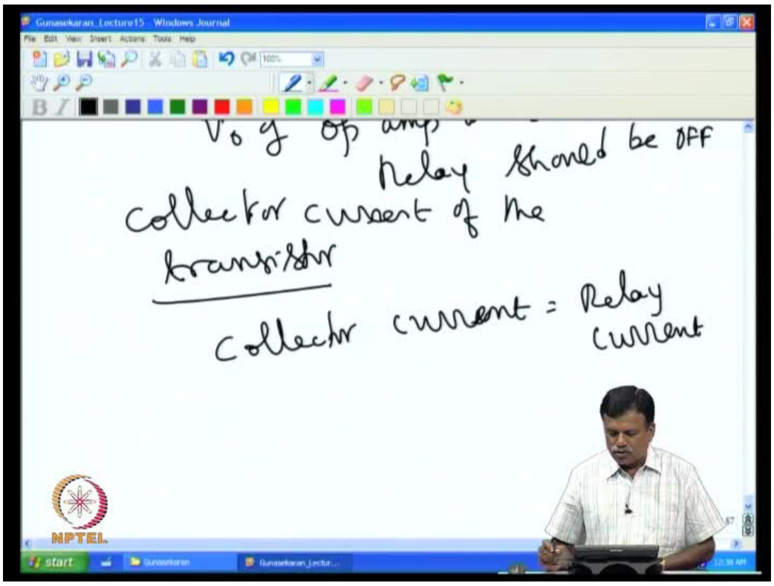

We had decided basically R 1 and R 2. Now, for these to decide, we should know what is the current that base is taking? We should decide on the base current, now base current have to decide, I should know the collector current, without worrying about temperature I will first fix what is the collector current required. We have to find collector current of the transistor, so that actually collector current is nothing but the load current relay current; so, collector current is nothing but a relay current. Now, the relay current is given by the relay manufacturer because only that much current flows the relay will be activated.

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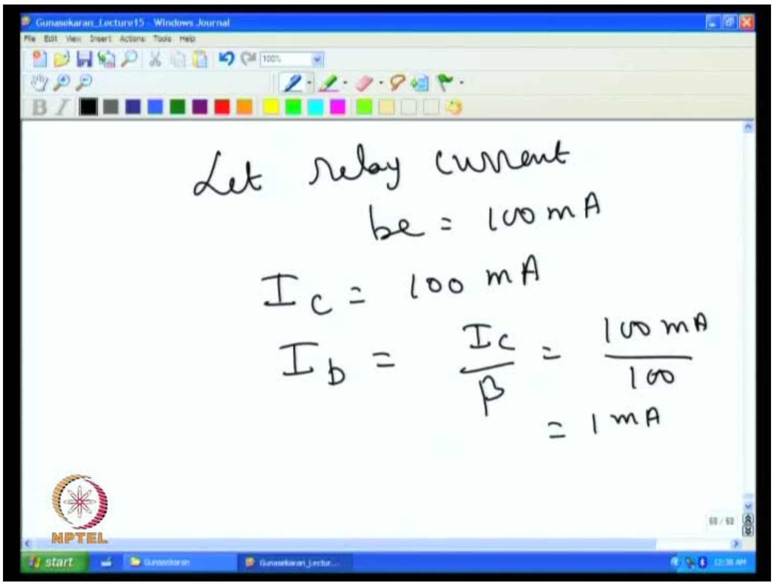

Assume, the relay current is in this case. Let relay current be 100 mill amps, you need 100 milliampere current that flow through the relay then only the relay will activate the contacts so taken relay current. Once, relay current is known, the collector current of the transistor is known that is 100 milliamperes. So, I c collector current is actually 100 milliampere, then transistor base current that will be I c by beta that will be 100 milliampere divided by assume beta is 100 then it will be 1 milliampere; so, end up in having a base current of 1 milliampere in this design.

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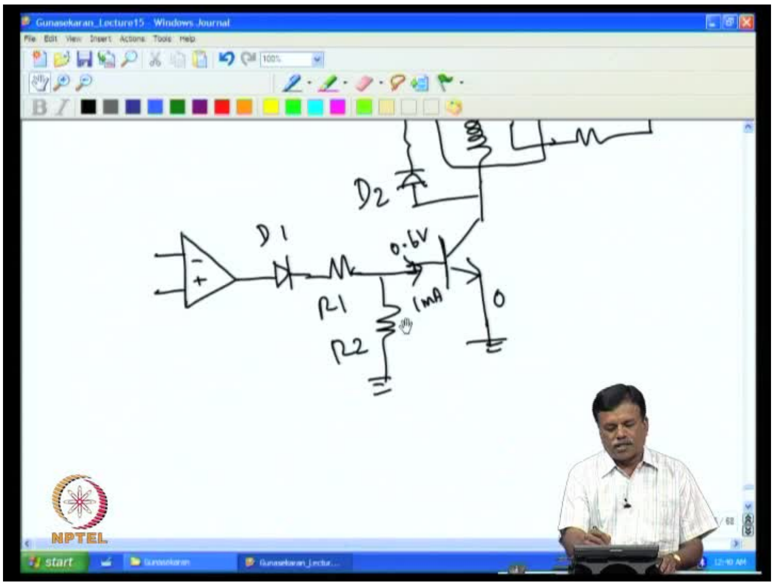

Once base current is known, then it would be easier to decide on the two resistors that is - R 1 and R 2, because now this current is known we have that this current is 1 milliampere, if it is one milliampere and then we know the transistor is on, this voltage is 0 voltage grounded, and this will go to 0.6 volt. This is 0.6 volt and we know the current is 1 milliampere, the same 1 milliampere current is flowing through that and then we know this resistance R 2 is used only to discharge. When the voltage goes minus, this become 0 but then storage charge in the transistor that is know the base emitter will have a capacitance that to be discharged, for that only we are using R 2.

The R 2 is actually can be large there is no problem because for example, if this is a few farad capacitor taking R 2 for example 10 k makes the discharge time is few millisecond or even less than that it will be only few nanosecond that kind of off time is fine because capacitor of 100 pf and then 10 k 100 pf is 10 power minus 10, 10 k is 10 power 4; so, you will have a switching time of 0.1 millisecond, if the capacitance the base emitter capacitor is 100 pf.

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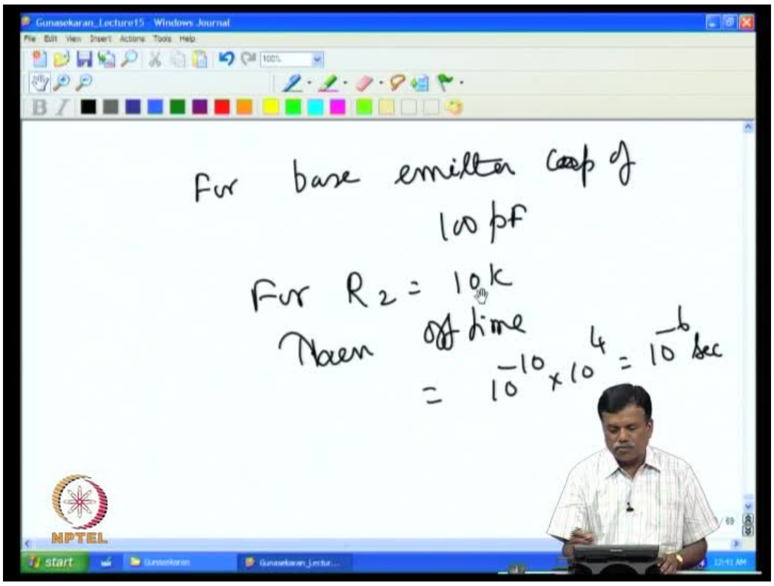

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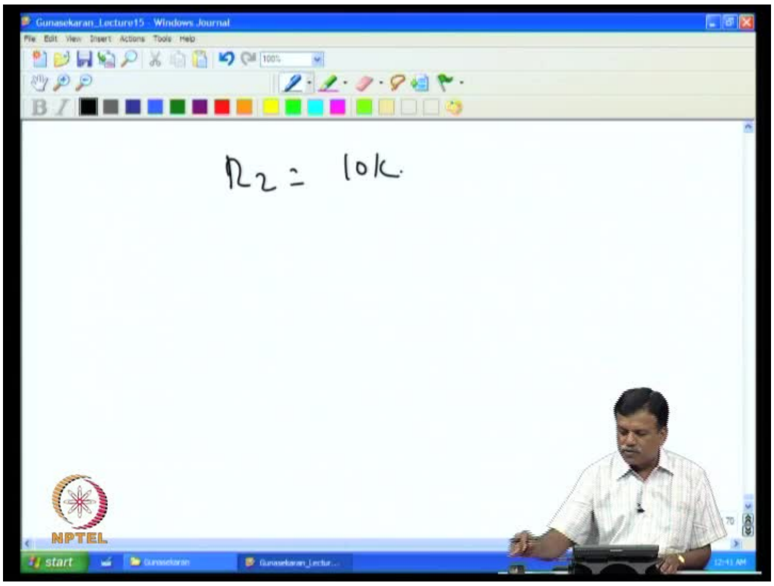

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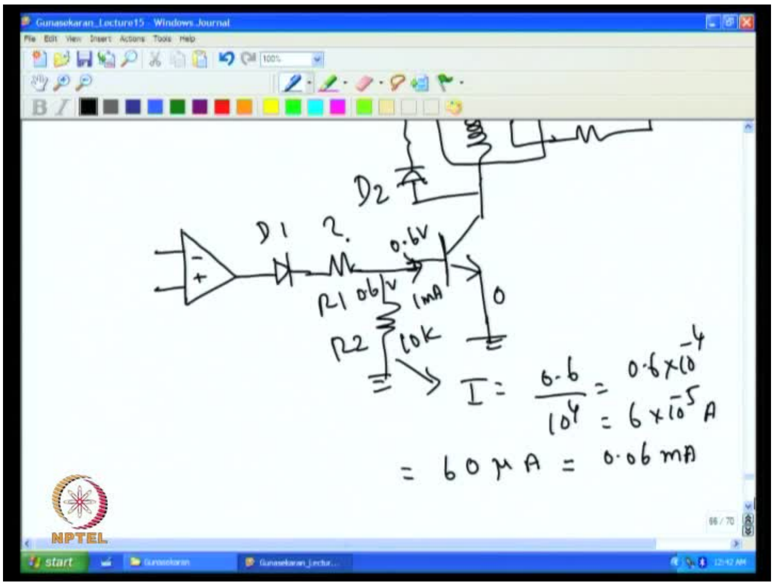

For base emitter, capacitor cap of 100 pf for R 2 is equal to 10 k then switching then off time. Off time comes to be 10 power minus 10 into 10 power 4 that comes 10 power minus 6 seconds, which is quiet fast so need not go much larger than 10 k. If it is not enough, we can readjust because this R 2 is in our control, this is our selection. So, we can select even larger value if the time very short, this is fine. So, R 2 is fixed, we got R 2 as 10 k which leaves us only to decide the other resistance that is R 1 because this resistance is 10 k now and we had decide on this value.

Now this is a 10 k, that means, this voltage across at this point is 0.6 volt, current through this is 0.6 by 10 k, this is 1 milliampere current is going and here 0.6 by 10 k. So, the current here would be 0.6 divided by 10 power 4 that will be 0.6 into 10 power minus 4 that will be equal to 6 into 10 power minus 5 amps that will be equal to 60 microamps or in a milliampere wise that comes 0.06 milliamps that is the current that is flowing when it is on. So, if this is at if this current is one milliampere, this current is 0.06 milliampere then total current R 1 will be addition of these two; so, the total current R 1 through R 1.

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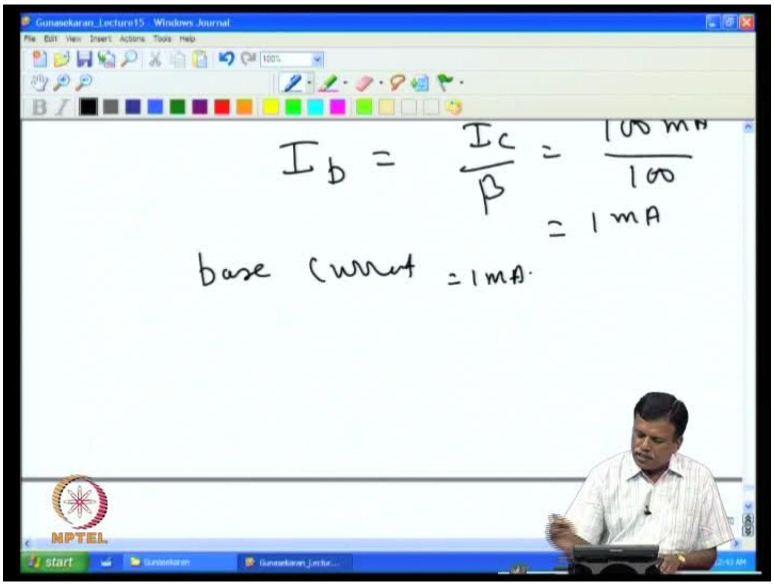

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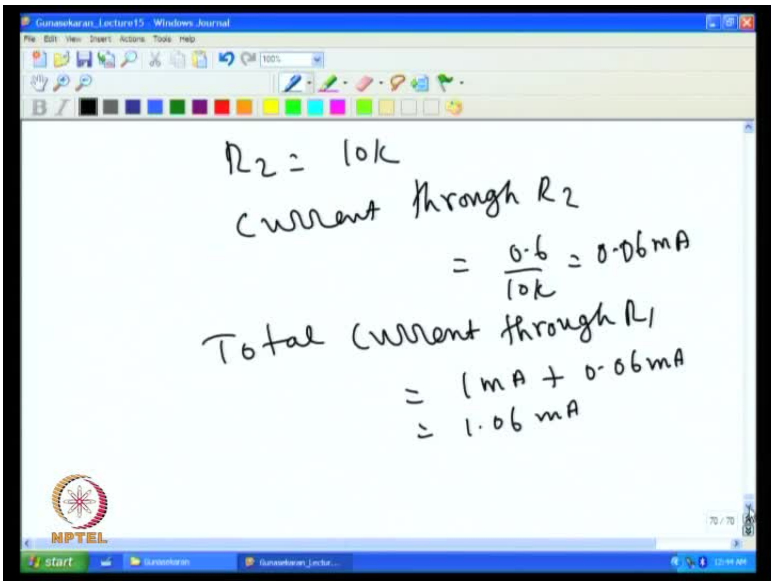

The base current is 1 milliampere then the resistance R 2 is 10 k, current through R 2 is actually 0.6 by 10 k that was worked out to be 0.60 milliamps, the total current through R 2. The total current through R 1 that is equal to 1 milliampere plus 0.06 milliamps that is equal to 1.06 milliamps. Now, we have to select the value of R 1, for that we should know what the voltage is across R 1.

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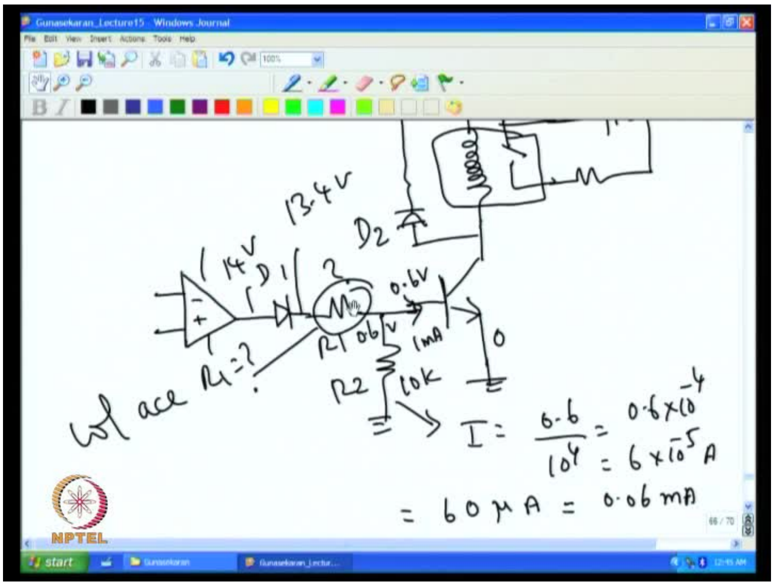

If you look at the circuit, the voltage across R 1 is voltage across R 1 we have to decide, we have to find the voltage across R 1. So if you look at the voltage across this R 1 we have to find out, if this operational amplifier is operated at plus 15, minus 15 normally we will get up to 14 volt here, when it is fully on you will not get 15. Normally, two diode drops less, you will have around 14 volt here and one diode drop is lost here; so, you will have here at this point roughly around 13.4 volt and this point is sitting at 0.6, that means, across the R 1 resistance at this end, we have 13.4 volt at this end, we have 0.6 volt that is at this point we have 13.4 at this end we have 0.6. So, voltage across R 1 turns out to be 13.4 minus 0.6 that is 12.8 volt.

Once you know the voltage across this is 12.8 and I know the current flowing through this, which is 1.06 milliampere; so, I can write 12.8 divided by 1.06 that roughly around you will get around 12 k resistance. The 10 k standard resistance available that can be used here, if you that means R 1 needs to be around 10 k that we can do it like this; so, if you show the calculations, it works out to be like this.

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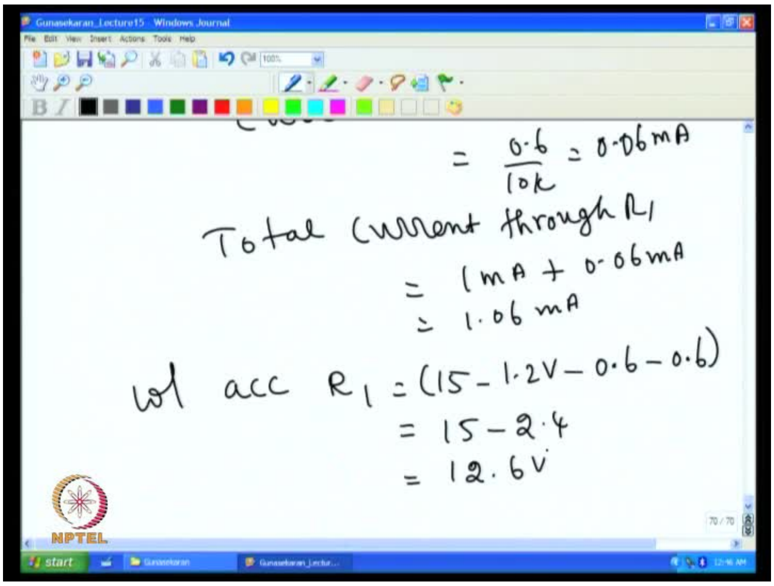

Voltage across R 1 is actually 15 minus 1.2 volt voltage across that is lost on the op amp minus 0.6 that is on the diode D 1 then minus 0.6 that is the base voltage; that is the voltage across the R 1 which works out to be 15 minus 2.4 that turns out to be 12.6 volt.

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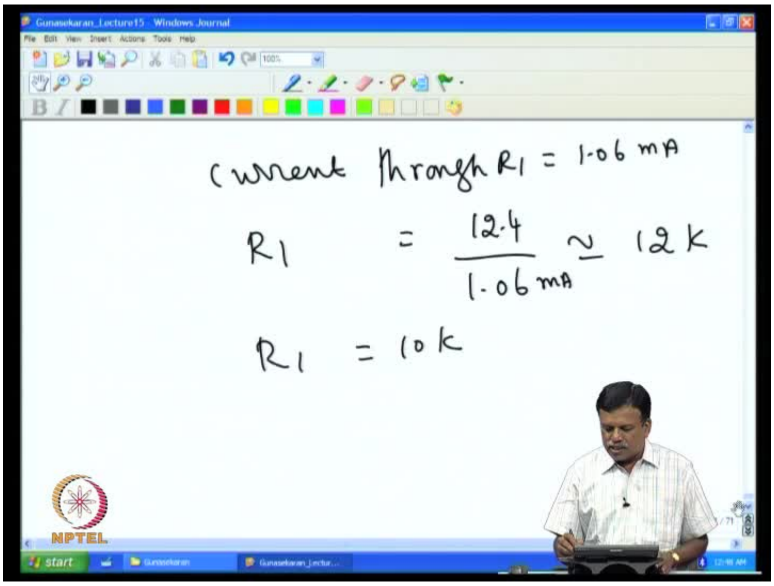

Current through R 1 that comes out to be 12.4 that is 1.06 milliamps; so, we can write R 1 is equal to 12.4 divided by 1.06 that I can roughly take it as 12 k, this is milliamps. I can take R 1 as 10 k other 10 k what you get a secondary value because it should be little wire than 12 k then only even at high temperature you will able to supply the enough current; so, R 1 to be decided like this. We had shown one example for switching that how to design a transistor circuit for switching? Because this kind of switches are very often used nowadays in analog circuit to switch on, off a relay or some other circuit

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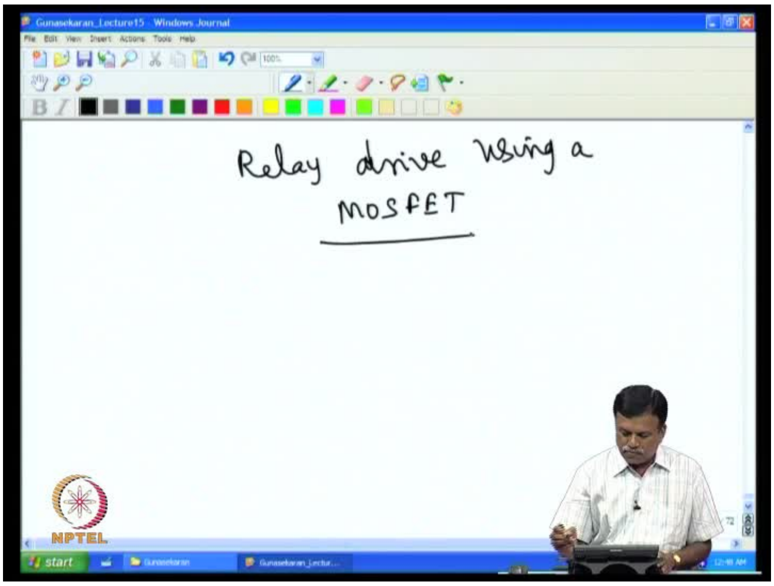

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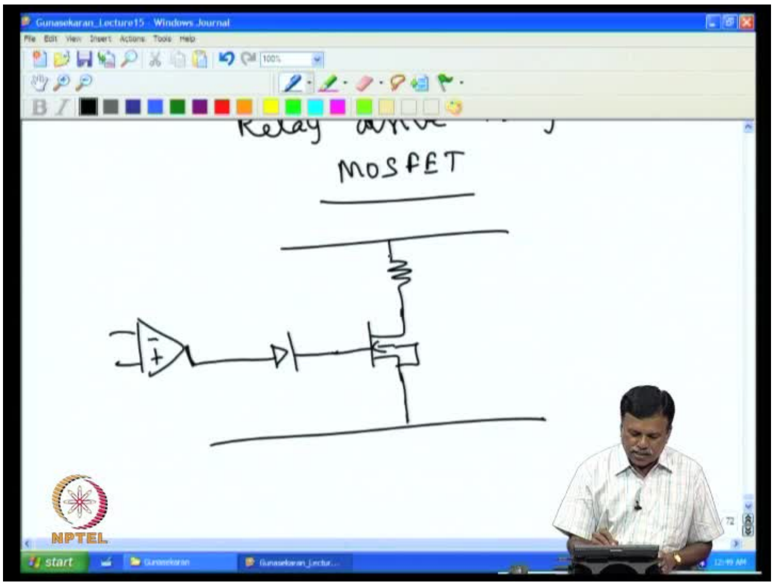

We actually do one more design, such that we will understand this circuit design much better. For example, we can do the same design using a MOSFET; for example, I want to drive the MOSFET I want drive a relay using a MOSFET. How will we go about designing this relay drive using a MOSFET?

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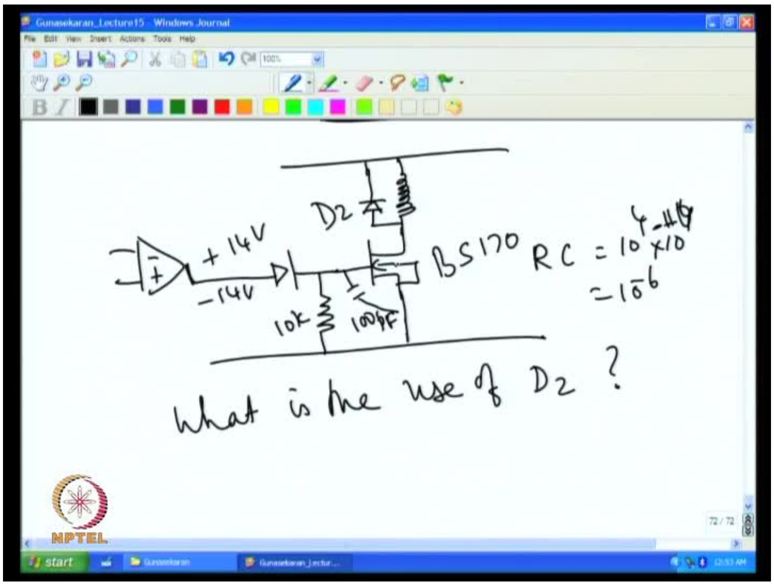

The general circuit looks like this, and then I can have this, I have this, then assume the same operational amplifier circuit here which gives me the voltage so I want to drive the MOSFET here, I connect, minus I do not want to apply so I can do this, I can connect this one directly, it is not a current operated device it is a voltage operated device and this is a supposed to be a relay; so, I remove this resistance I connect the relay (Refer Slide Time: 46:11). One small thing I did not explain that happened in the other case, what is the function of this diode? In this design, I will explain the function of this diode in detail.

We have this one, so when it is plus 15 volt it goes high, it will almost get around 14 volt, this is 14 volt you will be getting and then after one diode drop, you will get about 13.6 volt, the MOSFET will be on and we need not worry about the current. Then, when it goes to minus 14 volt then this diode will be off and you will get no voltage here, but the diode will not allow but the MOSFET is having a capacitor and that capacitor cannot be discharged. So, even when it goes minus 14 this capacitor will be holding the charge, the MOSFET will be continuously on, it will not go back; so, we have to provide a path for the MOSFET to on, go off; we have to give one resistance here because here we are not bothered about switching speed, because we are switching the relay once in a while you know once in few seconds or once in a minute only you will be switching; so, the switching time can be few milliseconds that is not a problem.

The switching off time would be this capacitor, for example if it is 100 pf and then for example, if I have 10 k resistance then the time would be RC time that would be equal to 10 power 4 into 10 power minus 10 that will be 1 microsecond 10 power minus 10.

The time constant actually comes out to be 10 power minus 6, in few microsecond time, in few time constant it will discharge. So, off time will be only few microsecond that is good enough for this application. For example, we have the MOSFET BS170 is there which switches on at 5 volt ,15 volt is not an problem and then going off is done by this; so, using a MOSFET designing, a switch function is easier.

But one problem with using MOSFET is, if the supply voltage is small, for example, if the supply voltage circuit is supposed to operate in only plus or minus 2 volt or 3 volt, low voltage applications then the output voltage you get will not be enough to drive the MOSFET; because if we get only 2 volt, with 2 volt the MOSFET will not be switched on, whereas transistor needs only 0.6 volts to make it on, the base emitter voltage it need only 0.6 volt, even low voltage applications you will not able to use MOSFET to switch on and off the relay. In high voltage applications, it can be MOSFET can be used, because even BS170 needs minimum 5 volt to make the MOSFET on and then with 15 volt or it can take up to 15 volt there is no problem. Actually, applying more than 5 volt to the circuit as long as we are not exceeding 15 volt, this is perfectly alright. Only thing is, now I have to explain, what is the function of this diode which we have not done, it even in the other case.

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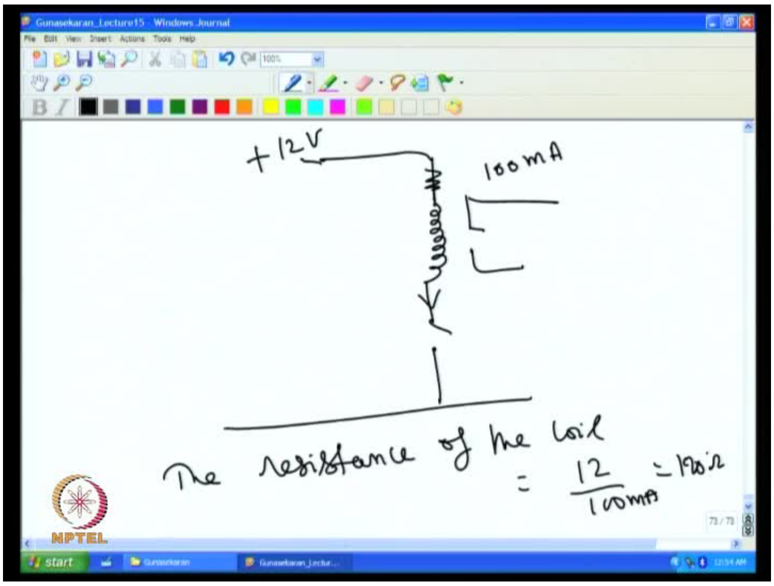

We will explain, what is the purpose of this diode? What is the function of this diode D 2? What is the use of D 2? Actually, if we do not use D 2, we already explain that this MOSFET or the transistor which is used in the previous example actually goes bad. What you do is that we explain the mechanism behind what is happening here, suppose if I have a switch here either MOSFET or transistor and if I say for example, supply is here plus 15 volt or plus 12 volt, then when the switch is on then the current flows through this and then this relay, because as a current capacitor of 100 milliampere we set this relay is a current carrier 100 milliampere.

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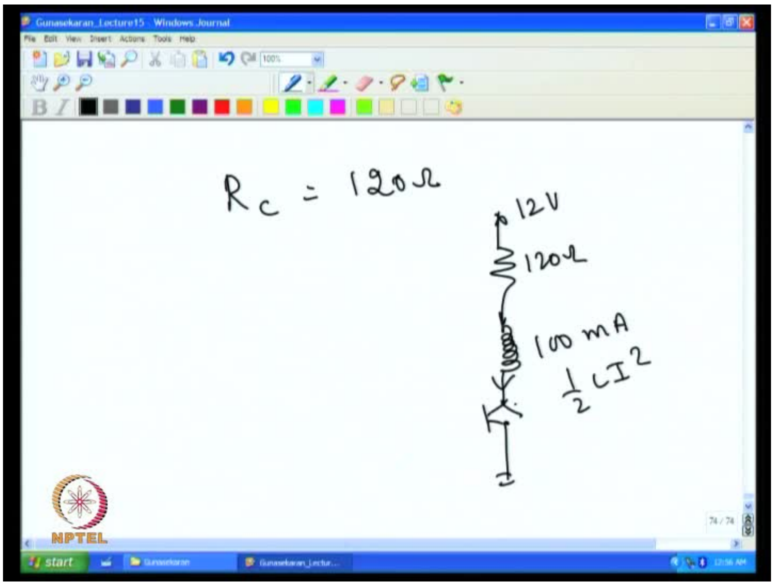

If this operating voltage is 12 volt, then in actual case the resistance of this coil, the relay as a coil actually the resistance the coil relay is the coil and the coil has a resistance and that 100 milliampere. Actually, if it is relay specified 100 milliampere and 12 volt then the resistance of the coil would be 12 divided by 100 milliamps that will be 120 ohms; so, the resistance of the coil, R coil is 120 ohms.

When you switch off and then it also act as an inductance. If you look at the circuit then it look this, we have here 12 volt, this relay is operated at 12 volt, this is 12 volt and this is 120 ohms and this act inductance (Refer Slide Time: 51:34). When switch is on, the current flowing through that is 100 milliampere because after a long time then current flowing through that will be, 12 by 120 that is 100 milliampere that is the current, that is flowing through this and then if you look at this, there is current flow through the coil and then there it has a inductance so that energy stored in the inductance is half l I square; so, energy stored in the inductor is half l I square. When current is flowing through that the energy stored, if we take in the inductance it will be about 40 to 50 millihenry, inductance will be there and I is 100 milliampere; so, certain amount of energy is stored in this and then the current is flowing like this (Refer Slide Time: 51:34).

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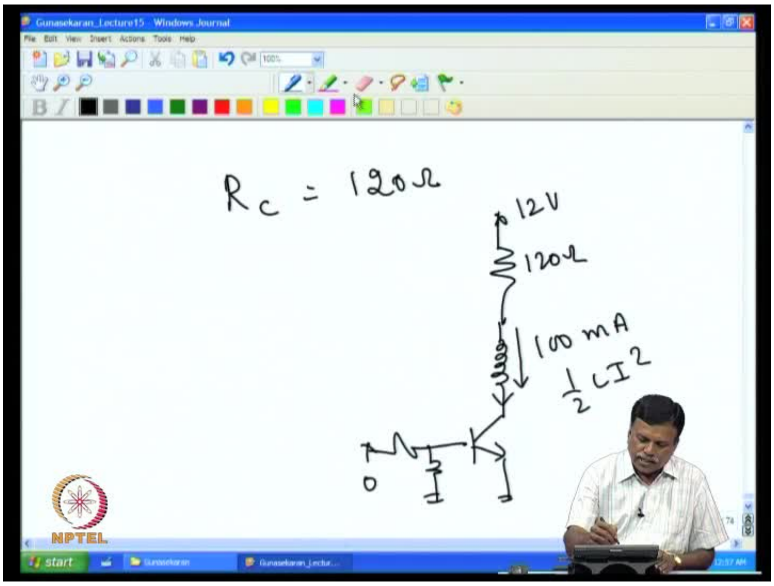

When you switch off this, for example, either MOSFET or transistor, if I remove for example if it is a transistor, so if I redraw with the transistor then you have the inductor and then you have the transistor here, it is on this. When the current 100 milliampere is going when you switch off that is, I remove this voltage to 0, take it to 0 then this transistor goes off then whatever current that is flowing here cannot go anymore in this, that means, when current was flowing magnetic field was build up in the coil and that energy is actually stored in the magnetic field. Now, I switch off this, then whatever current is flowing through this, have to find cannot go through this because the switch is not allowing that current flow.

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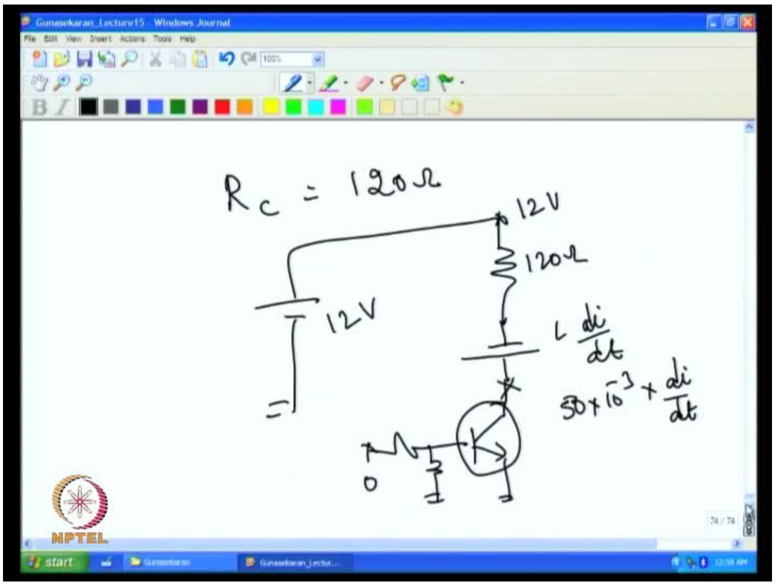

We are trying to interrupt this flow of current, that means, the current start decreasing, but that decreasing current will produce a decreasing magnetic field; because current decreases the magnetic field also will decreases, then decreasing magnetic field will induce a voltage in the coil. Let us say self-induced voltage, so as soon as you start switching of this, the magnetic field started collapsing and a collapsing magnetic field induced a voltage in this coil that polarity will be actually aiding the input voltage. If I draw that, that polarity will look like this, if I remove this and draw the decreasing magnetic field, and then draw the voltage. Once, I remove that and the decreasing magnetic field will putting a voltage. This is the voltage that you applied and then the decreasing magnetic field will apply a voltage like this, this is nothing but L into di by dt that is the voltage induced in the coil because of the decreasing current because current is decreasing and then because of that it is inducing a voltage.

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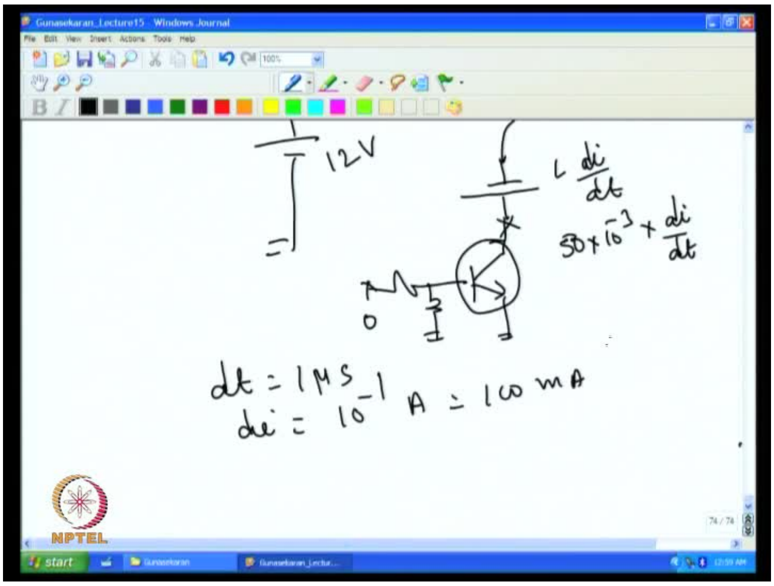

If I switch off this, the voltage at this point is sum of this voltage and this voltage, so this is actually 12 volt ,this actually depends on what rate that it is switching, what is di by dt. Assume that, L is a 50 millhenry; L if we take 50 millhenry then into di by dt is the induced voltage, if I take that then di by dt. I can take for example; this transistor switches off in 1 microsecond that is how we had decided earlier. If the switching off time that is dt is actually 1 microsecond then current change is 10 power minus 1 that is equal to 100 milliamps, because the relay current is 100 milliampere. We are trying to switch off 100 milliampere current in 1 microsecond so that comes out L di by dt.

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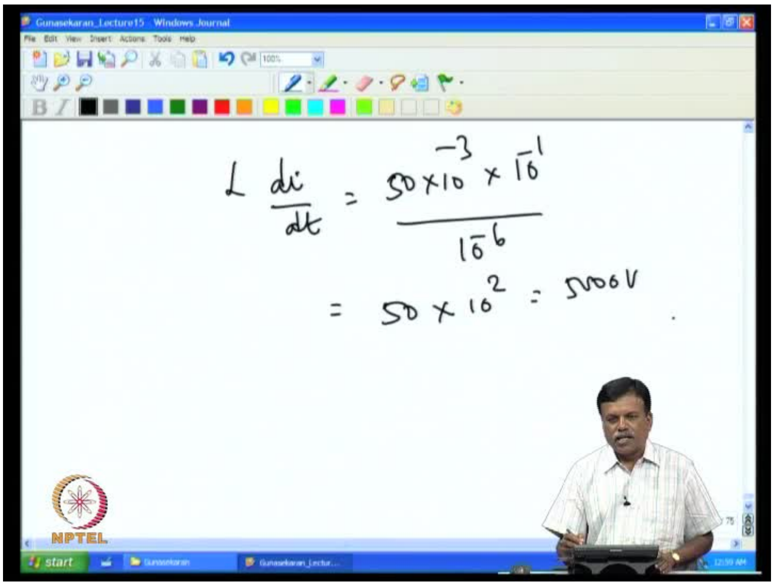

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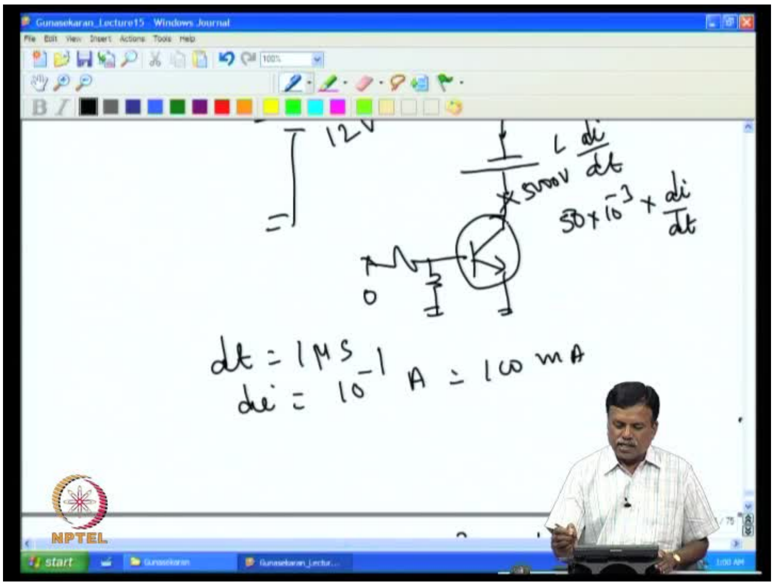

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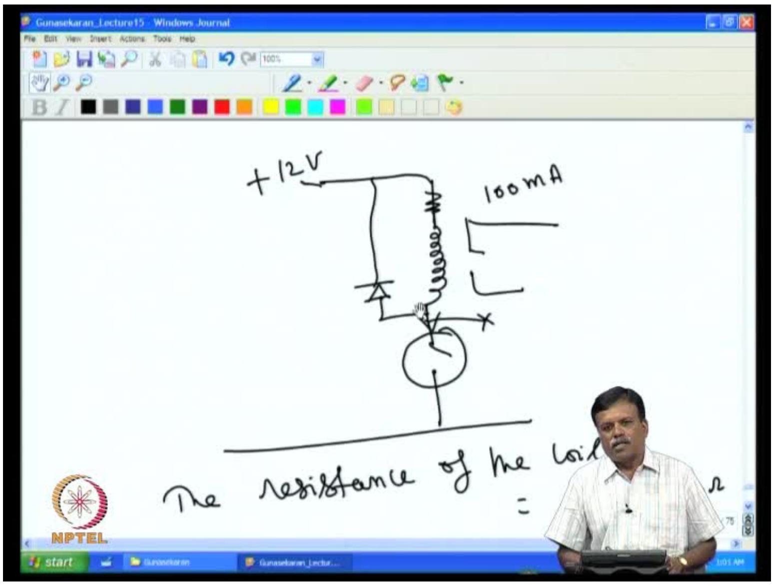

If you calculate L di by dt that comes out to be 50 millihenry. If I had taken then current of 100 milliamps 10 power minus 1 and dt is 10 power minus 6 that works out to be 500 into 10 power 2 that you will get 5000 volt, that actually, when you try to switch off the inductor abruptly, then you get this induced voltage going up to 5000 volt and such a high voltage this transistor cannot withstand, because V c break down voltage will be few 100 volt only we would have selected and 5000 volt destroys this transistor, that actually means, if I am switching the device like this with transistor, with the inductor with this switch then you get very huge voltage at this point and that will make the device to go bad.

If I want to protect then I have to use a diode here to protect this. So, once I put a diode the problem is solved, because when I switch off this switch whatever current that is going here trying to flow like this, because when the inductor if the current when you are trying to break the current, then as I said it induces a large voltage and that voltage is passed to here. Once this voltage goes, if this is 12, if this goes more than 12 then this start conducting this forward bias if this 12 and if once I switch off, the voltage trying to go up this once moment is go more than 12 then it starts conducting so that current will go like this and then go like this and continue to flow (Refer Slide Time: 56:54). In this resistance the 120 ohm, the heat is the energy is dissipated out it will take some time to circulate and dissipate all energy, but nevertheless voltage at this point will not go more than 12.6, because this is 12 and this will be limited to 12.6; so, the device will not go bad that is the use of this diode.

So, In this class, we had discussed how to use a transistor to amplify the signal, how to design various values to go with that, and also we had shown how to use the transistor as a switch, and how to use the MOSFET as a switch that also we had shown in the this class, and I also explained you what is the use of the diode which is to be connected across the relay coil. also explained So, with this I will stop, next class we see with other worked out examples, thank you.