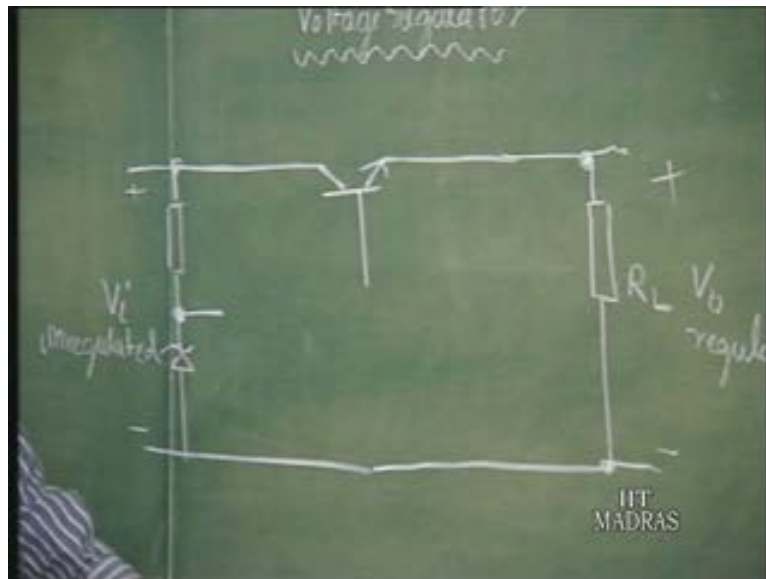


Electronics for Analog Signal Processing - II
Prof. K. Radhakrishna Rao
Department of Electrical Engineering
Indian Institute of Technology – Madras

Lecture - 27
Voltage Regulators (Continued)

We were discussing regulator, voltage regulator and we had seen how reference, Zener reference could be obtained and that could be fed as one input and the output voltage as another input to the base emitter junction, so that this current, the error current, is going to adjust the drop across the transistors so as to keep output constant at value of V_z minus V_{γ} . That simple regulator, we had discussed in detail.

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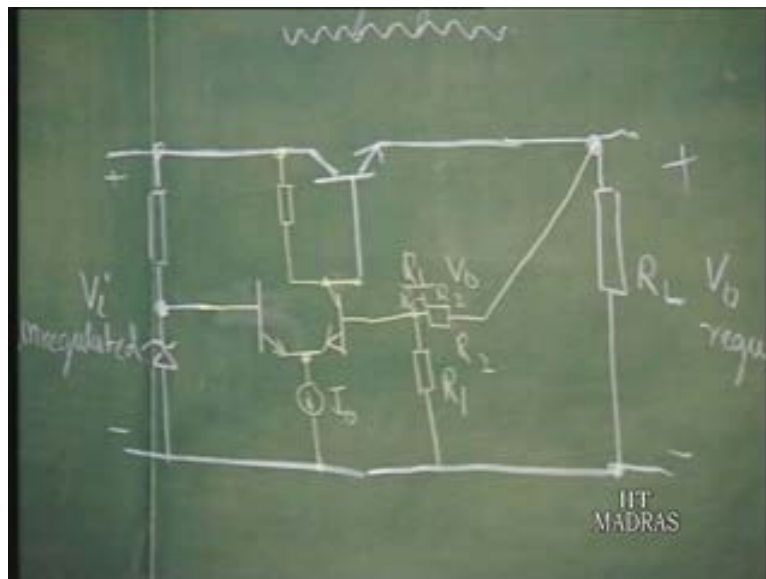


Now obviously, one limitation of that circuit is that V_{naught} was not adjustable once V_z is fixed; and also, V_{naught} was not exactly V_z ; it was V_z minus V_{γ} ; and it was dependent upon the base to emitter junction potential difference.

So, we would like to get rid of all these things and use an error amplifier and the error amplifier we said could be an op-amp comparator or simple differential amplifier. So now, we will use a simple differential amplifier which is a crude version of the op-amp itself. So, this is the difference amplifier here and the voltage that is developed across the load of the differential amplifier, that we will see is going to be taken to control the base...that is collector emitter voltage drop of the transistor.

So earlier, this was compared with this and that became the input; and now this...and portion of this...that is, this is being compared with, let us say, R_1 by $R_1 + R_2$ times V_{naught} ; portion of the V_{naught} , output voltage. This...this is a comparator which is nothing but a differential amplifier here. And let us say we are putting this as I_{naught} and this I_{naught} could be the current source which we can derive; we know how.

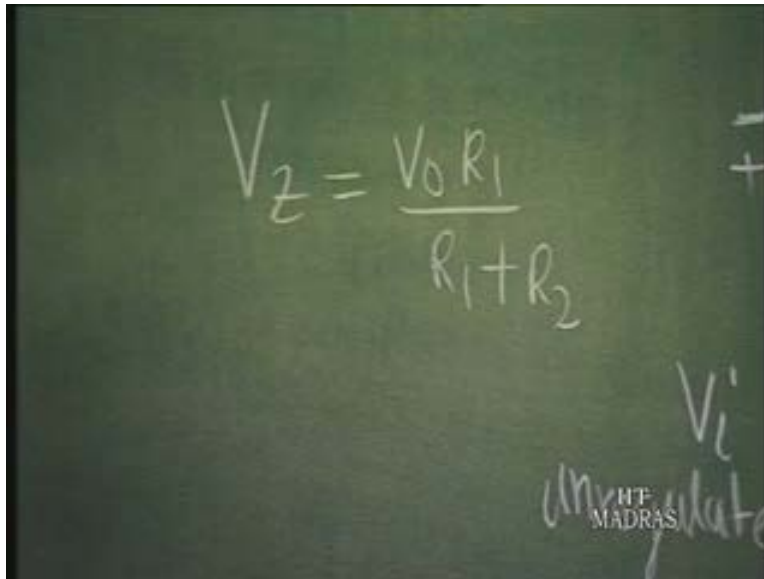
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So, this could be directly connected here. So essentially, we see here...either an op-amp or a differential amplifier could be used. From here to here, there is no phase shift; from here to here, there is a phase shift of 180 degree. So, this is minus terminal of the op-amp. This is plus terminal of the op-amp. This is the output of the op-amp. So, the output of the op-amp directly goes to the base. This structure, we had earlier indicated as the basic

structure, which will involve a voltage reference, a series pass transistor and a comparator, and the load. So actually, the comparator is comparing the voltage reference with portion of the output voltage. If therefore this is a negative feedback structure, then, if this is V_z , V_z should be very nearly equal to V_{naught} into R_1 by R_1 plus R_2 .

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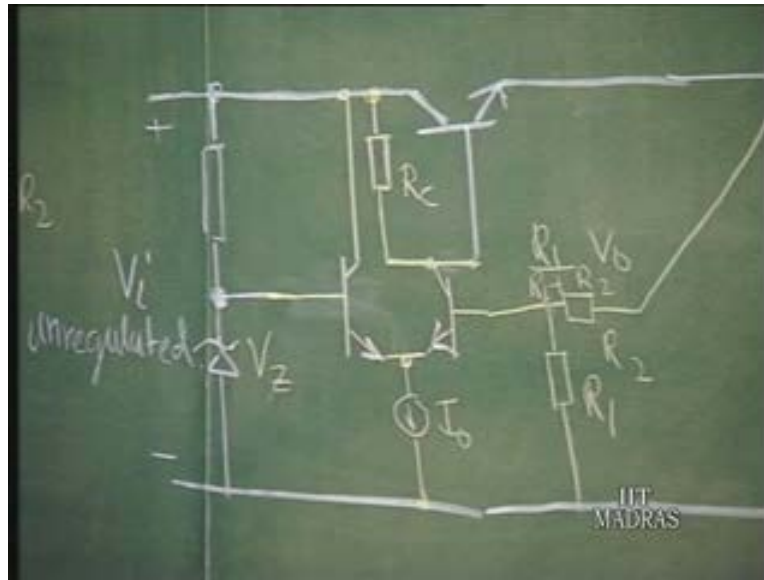

$$V_z = \frac{V_o R_1}{R_1 + R_2}$$

If the gain of the...open loop gain of the amplifier is very high, then this voltage should be same as this voltage.

So essentially, you can see that this particular structure is a very crude operational amplifier, using a single supply. The input voltage itself is biasing this operational amplifier. So, one end of the op-amp is connected to this end, supply; and the other one is connected to ground; output goes to the base of the transistor.

So, you will see that this configuration is normally available as a voltage regulator I C. The I C manufacturers have a differential amplifier and a series pass transistor and a voltage reference as part of the I C. So, this is a crude picture of a voltage regulator integrated circuit.

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So now, let us see what exactly happens. V_z is equal to V_o into R_1 by R_1 plus R_2 . So, V_o therefore essentially is equal to 1 plus R_2 by R_1 times V_z . So, depending upon V_z , once V_z is fixed, we can always find out what the R_2 by R_1 should be, in order to get the required output as the voltage regulated.

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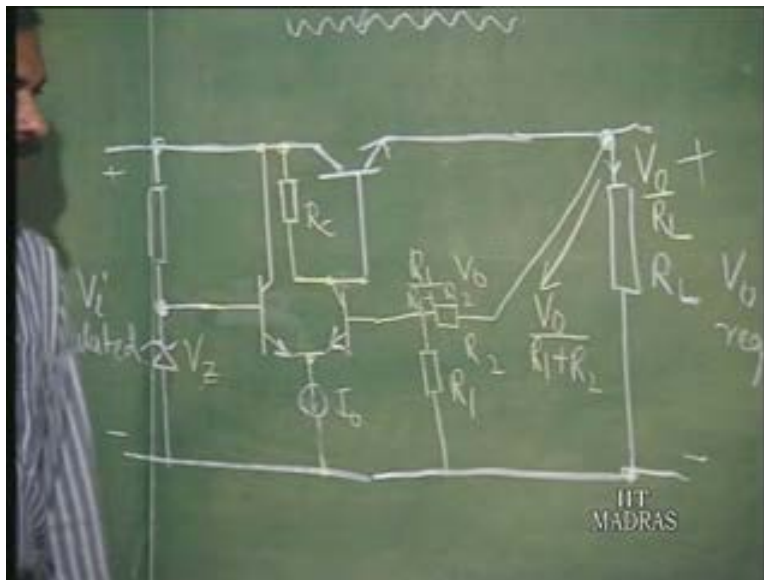
Handwritten equations on a chalkboard. The first equation is $V_z = \frac{V_o R_1}{R_1 + R_2}$. The second equation is $V_o = \left(1 + \frac{R_2}{R_1}\right) V_z$. The text V_i (unregulated) and the IIT Madras logo are also visible.

So, this is normally put externally. This network is put externally. $R_1 R_2$ network is put externally in order to fix the output voltage, regulated voltage, as what you want, given V_z . So, in every IC regulator also, V_z is specified so that you can fix according to your own requirement what the output voltage should be.

If this is the structure, that is, there in the...this thing...let us understand the structure fully. This is V_{naught} and this is taking a current of V_{naught} by R_L . That is the load current; and this takes a current of...assuming that the transistor Beta is high, this will take a current of V_{naught} by R_1 plus R_2 .

Obviously, R_1 plus R_2 should be chosen by us such that this V_{naught} by R_1 plus R_2 forms a small part of the load current, because rest of the current should not be dominant for efficiency, for maintaining good efficiency. So, this is made small compared to V_{naught} by R_L ; but this should be larger.

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V_{naught} by R_1 plus R_2 should be much less than R_L . This is one requirement. Then we have assumed that this current is V_{naught} by R_1 plus R_2 . That means this base

current is neglected. That means this should be greater than, much greater than the base current.

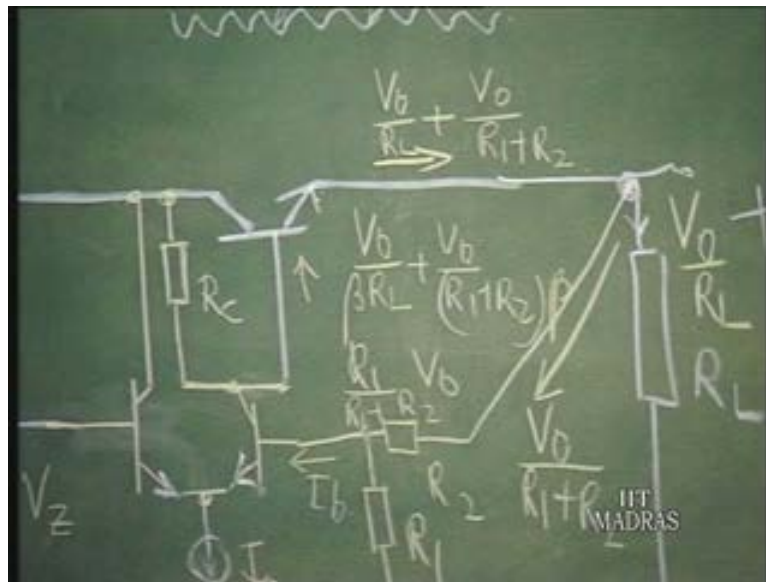
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The image shows handwritten equations on a chalkboard. The top equation is $I_b \ll \frac{V_o}{R_1 + R_2} \ll \frac{V_o}{R_L}$. Below it, there are terms I_{R_L} and V_o . At the bottom, the word "regulated" is written in cursive. In the bottom right corner, the logo "IIT MADRAS" is visible.

So, selection of R_1 plus R_2 is based on these requirements. It should be much greater than base current and it should be much less than the load current; and R_1 by R_1 plus R_2 - ratio is fixed depending upon the output voltage. So, R_1 and R_2 get uniquely fixed based on this.

Next, this current is nothing but V_o naught by R_L plus V_o naught by R_1 plus R_2 . Now, that current divided by Beta; that by...that is the current delivered by the base of this. Let us see what this current is.

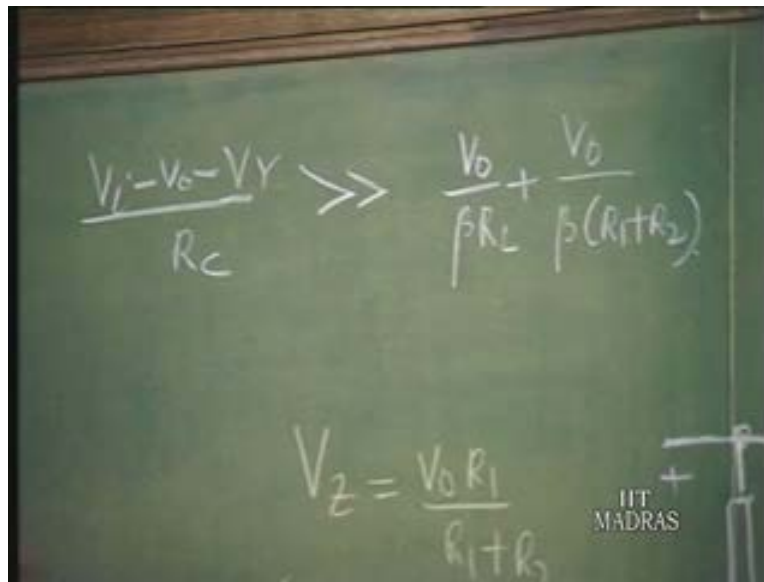
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This is at V_i , we know this potential; and this is V_{naught} , this is at V_{naught} , plus V_{Gamma} . So, the current in R_c , this current is V_i minus V_{naught} minus V_{Gamma} by R_c . So, this current keeps fluctuating as V_i is changing. One thing is this current has to be much greater than this current. This current is the one which is split between this and the transistor.

So, V_i minus V_{naught} minus V_{Gamma} by R_c ; this current should be much greater than V_{naught} by βR_L . Of course, this current can be ignored.

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$$\frac{V_i - V_o - V_Y}{R_C} \gg \frac{V_o}{\beta R_L} + \frac{V_o}{\beta (R_1 + R_2)}$$
$$V_Z = \frac{V_o R_1}{R_1 + R_2}$$

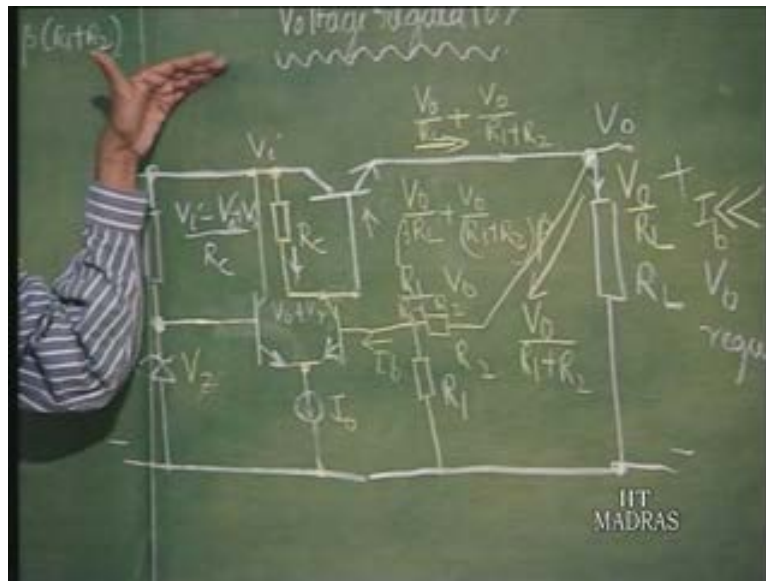
Now, by how much greater? - in the sense, this current should be capable of supplying this current and also there should be some current left out for this transistor to be in the active region.

That means this current should not also go too high or too small. It should be high enough so that it can give some current to this and some current to this, so that this current...transistor does not go off. If this keeps on increasing, this current remains the constant because V_{be} is constant. Rest of the current should go into this and this current can keep on increasing. So, what will happen? This transistor will conduct more and more. And ultimately, it will carry only a current of I_{sat} . That means it is capable of driving this transistor to half state. So, the...in the working of this regulator, we have to understand clearly the limitations on input voltage.

Now, for certain load here and output voltage, this current is constant. Let us say, this current is 100 milliamperes and Beta is 100, let us say. So, the base current is a constant requirement of 1 milliampere. So, this current has to be greater than 1 milliampere. Let us say it is 2 milliamperes for a given input voltage.

So, this 1 milliampere will go into this. Therefore, I_{naught} has to be greater than 1 milliampere so that some current is left out for this transistor to remain in the active region. So, as V_i keeps on increasing, this current will keep on increasing; and this current will keep on increasing and this will keep on decreasing.

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So, for a certain limiting value of V_i , this transistor will stop...the differential amplifier will stop functioning, because it will reach the limit of its current switching. Again, when V_i is kept on decreasing, this current will go to zero. That is the other one. So, because of this limitation itself, we will have a V_i max and V_i minimum that we can determine from these equations. So this current should be much greater than this and it should be less than I_{naught} . This is the requirement.

So, as far as this structure is concerned, we can as well put a current source here instead of R_c so that the open loop gain of this differential amplifier is high. Otherwise, the gain of this is simply $g_m R_c$ by 2. The gain of this is $g_m R_c$ by 2. g_m is 1 over R_e of the transistors. So, all these things you can assume, as long as the current division is I_{naught} by 2 and I_{naught} by 2. That I_{naught} by 2 division occurs only for a specific V_i situation. Otherwise, these two currents will be different and the g_m of the thing is 1

over R_{e1} plus R_{e2} and the gain is that g_m into R_c by 2; R_{e1} and R_{e2} will depend upon the currents sharing in this.

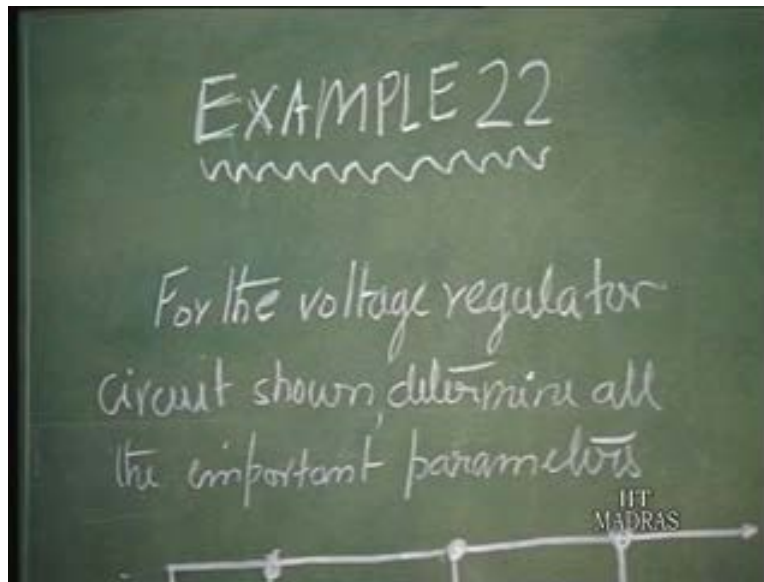
So, all these things you have to remember because it depends upon the operating point. The small signal definition of the equivalent circuit is based on the operating point and it is not necessary that this should operate at all times with equal division of current here. So, this is a D C amplifier actually. Voltage regulator is using a D C amplifier for regulation purposes; and therefore, the operating point keeps on shifting as far as this is concerned.

So, we will perhaps work out an example of this regulator and see for ourselves all the limitations that can come about in this circuit. And, as far as the output impedance is concerned, since this is using an op-amp in the negative feedback structure, it is much lower than the earlier output impedance which was nothing but R_e ; and R_e plus R_z by $\beta + 1$. Here it will be much lower than that; it will be lower than the earlier impedance by the loop gain.

So, we will work out an example and show the various parameters associated with the regulator.

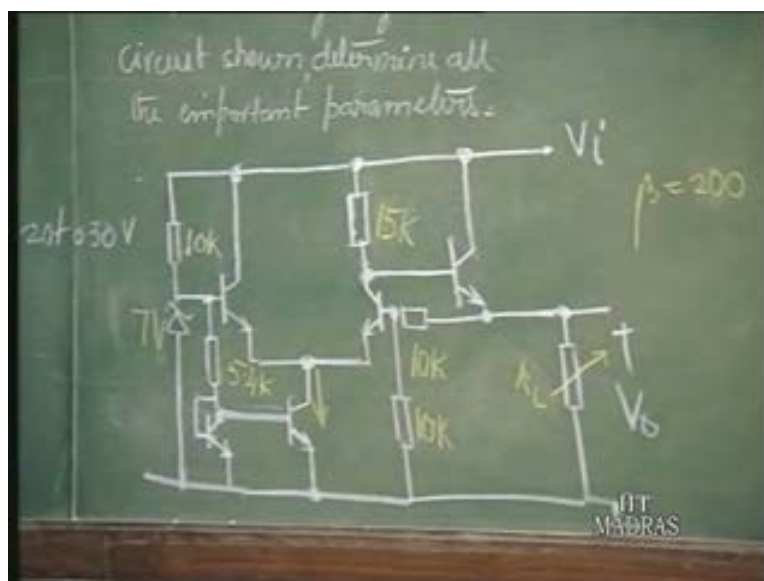
So now, consider Example 22. For the voltage regulator circuit shown here, determine all the important parameters which we have already defined earlier. So, this is very illustrative of what exactly happens in a typical voltage regulator circuit.

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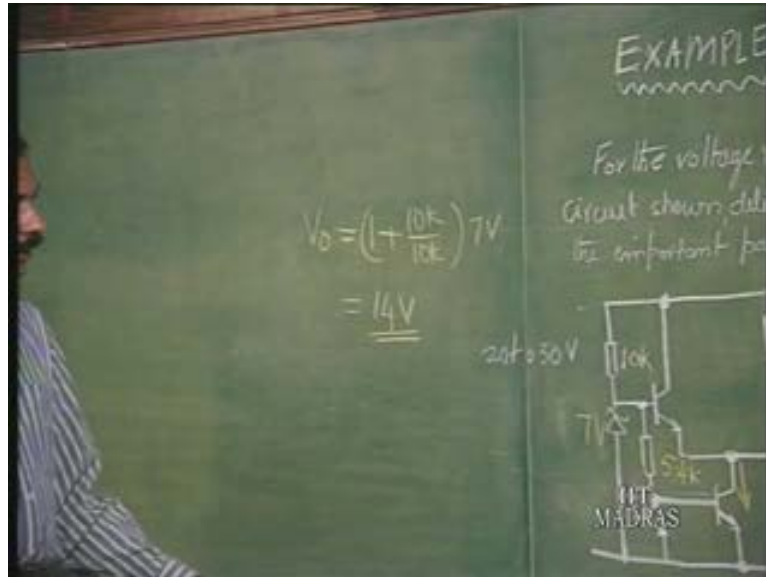
V_i is the applied unregulated voltage which let us say, keeps changing from 20 to 30 volts. This is the typical variation possible because normally, this unregulated voltage is derived from the power line and that much variation occurs in the power line and you are deriving from rectifier, transformer rectifier, filter and unregulated voltage which is going to supply to this.

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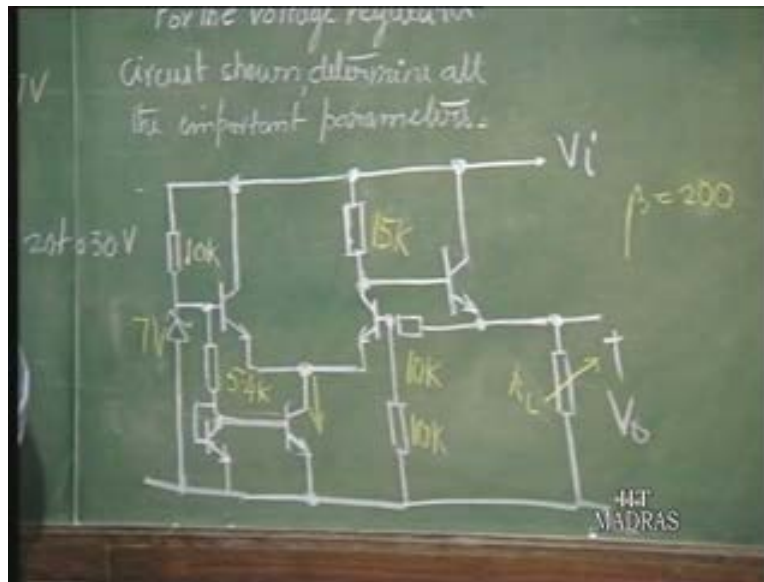
So, that is varying from 20 to 30. You want a regulated supply voltage of, let us say in this case, 14 volts because this is... V_z is 7 volts and R_2 is taken as equal to R_1 . 10 K, 10 K. So, $1 + R_2$ over R_1 is 2. So, 2 times 7 volts is the output voltage.

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So, regulated output voltage is 14 volts; 2 times V_z - that is gone. And let us say R_1 ...we would like to now know, how much current I can draw before this circuit starts failing, stops functioning as a voltage regulator.

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First of all, is there a minimum current, is there a maximum current, etcetera? So, the current drawn here is V naught by $R L$. So, it keeps changing depending upon $R L$. The first question that we would like to pose is what will be the limitation on $R L$ during which this will continue to function for an input voltage which is changing from 20 to 30 volts.

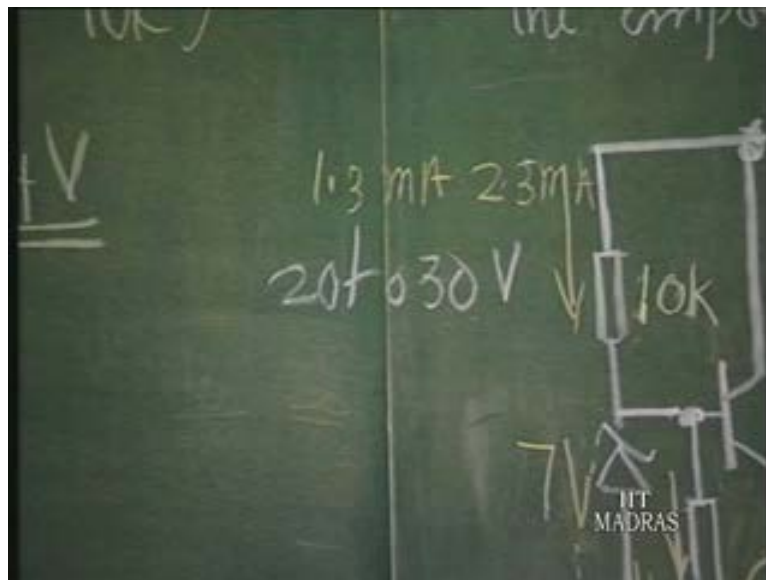
Let us now see other bias currents that are going to flow through this; whether our design is properly drawn. 7 volts is here and the voltage across this biasing arrangement is 7 volts minus the point 6 volts drop here for the diode connected transistor. This is a current mirror; point 6 volts drops here. So, 7 minus point 6 is 6 point 4; divided by 5 point 4. We will change this resistance suitably so that our current is some round number. Otherwise, we have to use calculator. 7 volts minus point 6 is 6 point 4 volts; and across 6 point 4 K we have 1 milliampere drawn here. This 1 milliampere is a constant current that is going to be drawn and therefore this is going to be 1 milliampere. That is made independent of the input voltage variation.

If we have connected this here it would have varied. We do not want that to vary. So, this current is made constant, bias current is made constant by connecting it here. So, this

current, of course, keeps varying here. This is the bias current needed for the Zener. Please remember, this has to be greater than 1 milliampere - here this current - so that some current is left for the Zener. This current is going to supply the Zener as well as this 1 milliampere.

So meanwhile, we are ignoring the current drawn by the transistor, of course. So, this current is going to be V_i which is varying from 20 to 30, divided...minus 7 volts divided by 10 K. So basically, this current is varying from, let us say 20 minus 7 is 13. 30 minus 7 is 23 by 10 K. So, it is varying from 1 point 3 milliamperes to 2 point 3 milliamperes. So, this current is varying; corresponding to this is 1 point 3 milliamperes; corresponding to this is 2 point 3 milliamperes.

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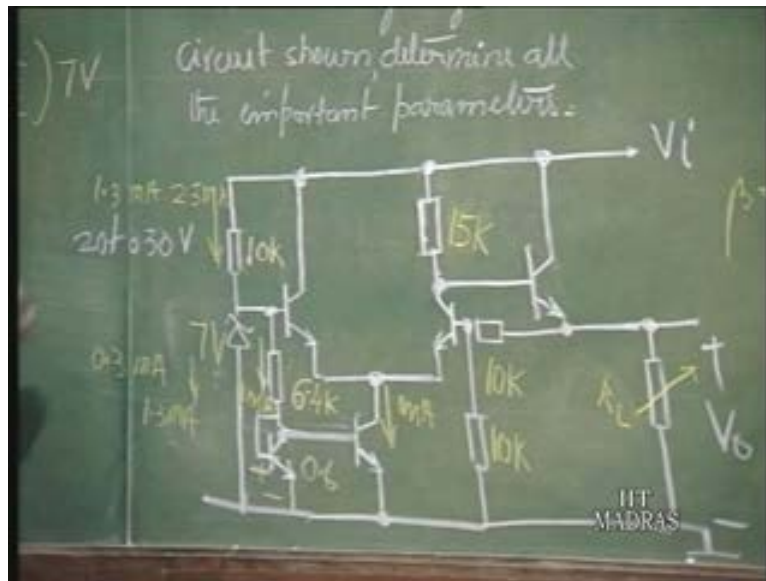


Let us keep a note of this because when 1 point 3 milliamperes is flowing, this 1 milliampere is taken away. The Zener is left with point 3 milliamperes. So, this current is going to vary from point 3 milliamperes to 1 point 3 milliamperes.

So, that information is very useful for us. When it is changing from point 3 milliamperes to 1 point 3 milliamperes, obviously, the Zener voltage will change. It will not be

constant at 7 volts. That change in Zener voltage is what is going to appear at the output as 2 times that. So let us say, at point 3 milliampere, it is some value - 7 volts; and at 1 point 3 milliamperes, it is 7 point 1 volt; higher. Then correspondingly, output will be changing from 14 to 14 point 2 volts. So, that is what is called as line regulation.

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So, as V_i is changing, output voltage is changing. So, we can therefore find out the line regulation factor as $14.2 - 14$ divided by 14 expressed as a percentage. So, that is the line regulation factor for this circuit.

So, line regulation can be found out from the information about Zener voltage change here. So, let us say this...at point 3, it is 7 volts Zener and this at 1 point 3, is 7 point 1 volt. So, output voltage is going to change from 14 volts to 14 point 2 corresponding to this. So, line regulation factor is going to be $14.2 - 14$ by 14 . So, that is equal to 0.2 by 14 , expressed as a percentage. That means that into 100 .

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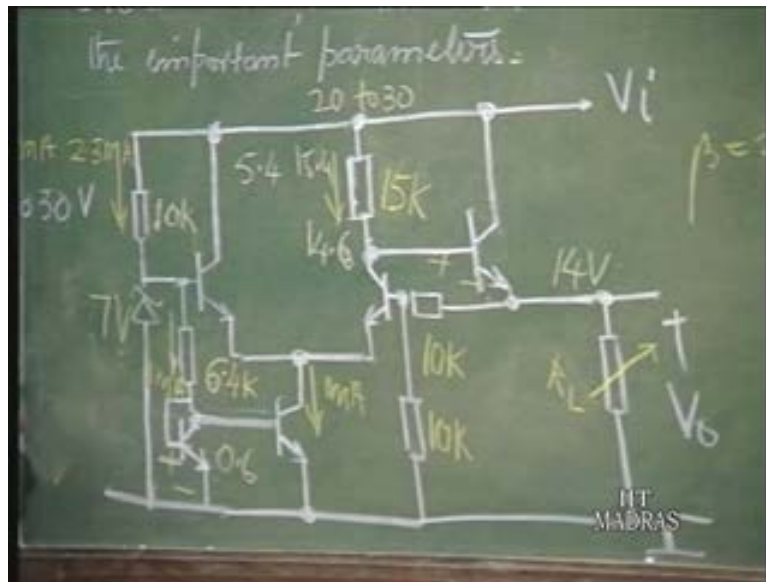


So, it is really 20 by 14 or 10 by 7 which is 1 point...how much is it? 1 point 4 percent. So, that is what is called as line regulation factor for this circuit. So, please understand this is one way. Because of line voltage variation, output voltage can vary, direct. Other way is also through the link here because this is not a truly very high impedance point. This...there is a reverse bias junction here. Then it is connecting.

So, if the reverse bias impedance is not too high, then there will be transmission on this side also. So, all these factors will come into picture; but the primary factor in this circuit, I told you...because compared to this impedance, this is very low and therefore most of the transmission occurs through this path.

Next, we will also know what is the variation of current that is occurring here. That is, this we had mentioned about earlier. Because V_i is changing from 20 to 30 volts, the current here is changing. What is the voltage here? This is 14 volts and this is 14 point 6; let us say, V_{γ} more. So, this voltage is going to change. This is going to change from 20 to 30. That means this voltage across this is going to change from, let us say 5 point 4 to 15 point 4 volts. So, the current is correspondingly going to change from 5 point 4 by 15 to 15 point 4 by 15. What is the value?

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Current is going to change. That is most important for us. 5 point 4 by 15 to 15 point 4 by 15 milliamperes. So one is, this is point 36 milliamperes and the other one is 1 point zero 3, 1 point zero 3. So, the point 36 to 1 point zero 4 something... So, this is the variation of current in this.

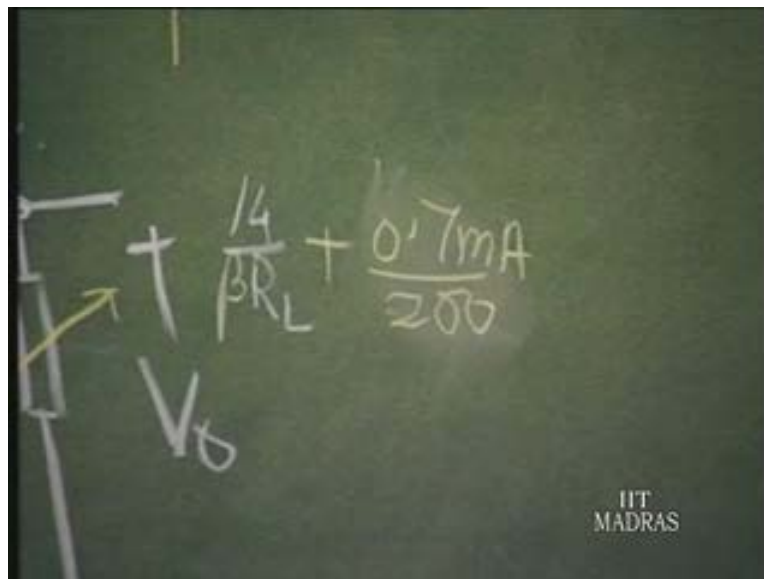
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Now, what is the current demanded by this is what is important, so that we can find out how this works here. This load is going to change. That we said. To what extent we can change the load so that this circuit still functions? This is an interesting point so that you see exactly how this circuit functions, trying to maintain 14 volts here. So, the current in this is 14 by R L.

So, 14 by R L plus, of course, 14 by 20 K. This current, 14 by R L plus 14 by 20 K - 1 point naught 3. That does not matter; not much of a change. So, 14 by R L plus 14 by 20 K, which is how much? This is point 7 milliamperes. So, what should be the range of variation of R L so that this transistor, this circuit still functions satisfactorily? This divided by Beta. Beta is given as 200. So, this divided by Beta; this becomes a very small part of the current, you can see. Now we have to concentrate on this 14 by Beta R L.

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So, this current is being delivered here; base current of this. Now, let us consider. It should keep functioning at all times, let us say. This current is changing from point 36 to 1 point zero 3; the current required for biasing this is totally equal to 1 milliampere. So, when this is point 36, what can happen? Let us see. When this current is point 36, what can happen? This can demand most of it. So, and therefore, this is left with almost

nothing. So that means, point 36 is going to be one limit of current where this is left with almost nothing and this point 36 is straightaway going into this. That means point 36 into Beta, that is 200 is the maximum current this can deliver. So, or this current can be equal to point 36, limiting situation, R into Beta. That is 36 into 2 - 72 milliamperes. That is the maximum current it can deliver under that situation. If you demand more, there is nothing to give that, under the situation that this is point 36 that corresponds to input voltage of 20 volts.

So, you can now see that R L should be greater than some value because this you can now find out. 14 by R L should be equal to 72 minus point 7. That is, 71 point 3. So, R L should be greater than 14 by 71 point 3. The...this is in terms of Kilo ohms, K. So roughly, this will be equal to about 200 ohms. How much is it? 196. So, this is equal to 196 ohms.

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The image shows a chalkboard with handwritten mathematical equations. The equations are:

$$\frac{14}{R_L} + 0.7 \text{ mA} = 0.36 \times 200$$

$$V_{\beta} \frac{14}{R_L} = 72 \text{ mA}$$

$$R_L > \frac{14}{\frac{72}{11.3}} \text{ K} = 196 \Omega$$

The chalkboard also has the IIT MADRAS logo in the bottom right corner.

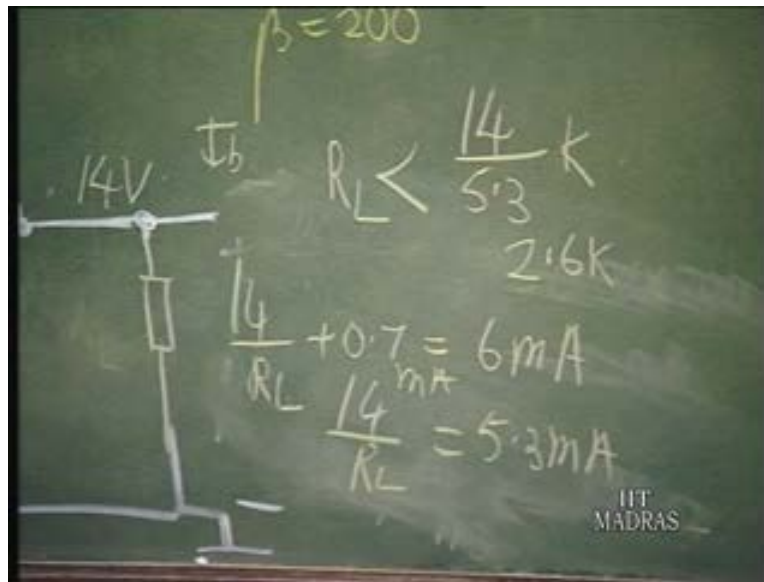
That means R L has to be greater than this. If it is less than this, this circuit will stop functioning for input voltage of 20 volts.

Obviously, it will happily work if R_L is 196 ohms with 2 point 3 milliamperes. That is 30 volts because 30 volts corresponds to 1 point zero 3; and this is demanding only point 36. Rest of it can go into this. That is 1 point zero 3 minus point 36, whatever it is. That is, about point 64 can go into this very happily because it still has some current to be given to this; that is point 36. So, this circuit will function up to this kind of load; lower than this, it will stop functioning.

Now, we can also determine the maximum limit; that is R_L max. The...that will deliver the lowest current. Obviously, can we...can we see whether it can be open circuited. We will see. Suppose R_L is open circuited. Nothing is demanded from it. Then what happens is this current is zero. The only current that is to be supplied is point 7 milliamperes for this biasing circuit; point 7 milliamperes divided by 200, extremely small.

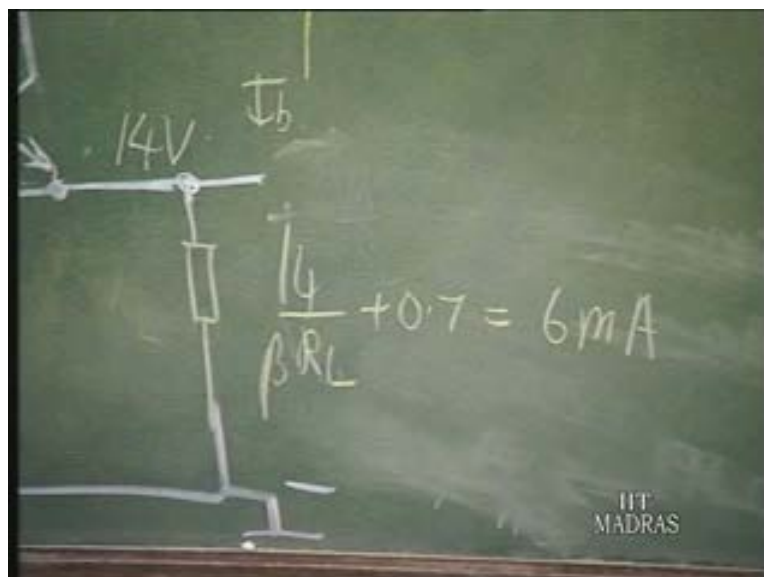
So, most of the current in this will go into this. That is alright as long as it is point 36, because if this point 36 going...goes here, point 64 will go into this. No problem. But, if 1 point zero 3 goes into this, there is a problem because only 1 milliampere should have gone here and there is nothing that will take the rest of the current. So, that means it has to deliver the rest of the current to this. That means it is not possible to have open circuit here. So, there is a maximum value for R_L also. So, we will find out that.

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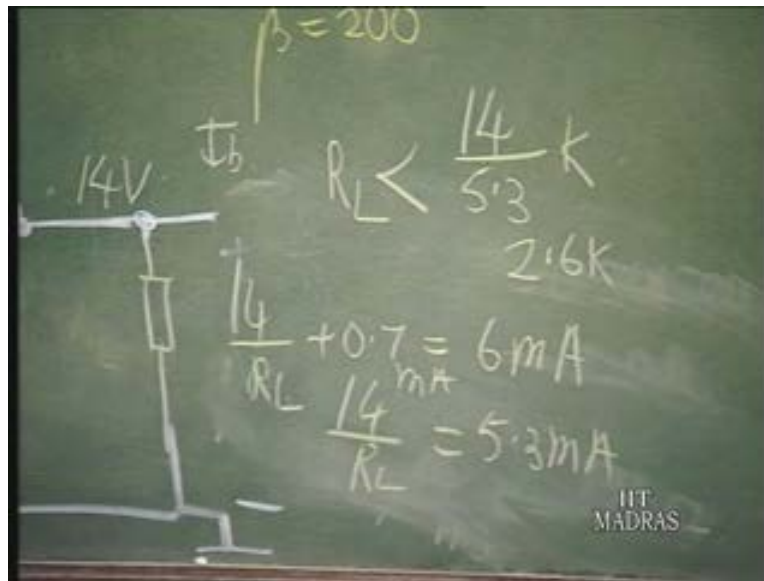
So, we have 14 by R_L divided by Beta plus point 7 becoming equal to, let us say it is 1 point zero 3 here because it is of no consequence to discuss it for point 361. Point zero 3, when it is highest here, 1 milliampere is taken from this. Point zero 3 will go to this. If point zero 3 goes 200 times, that will appear there. That means 6 milliamperes will be appearing there. So, this current can be at the limit equal to...lowest value is 6 milliamperes.

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Point zero 3 comes here, into 200 is 6 milliamperes. So, this 14 by R L... This Beta is already taken. 14 by R L plus point 7 milliamperes is equal to 6 milliamperes; or this is 5 point 3 milliamperes; or R L should be less than this 14 divided by 5 point 3 K - 2 point 6 K.

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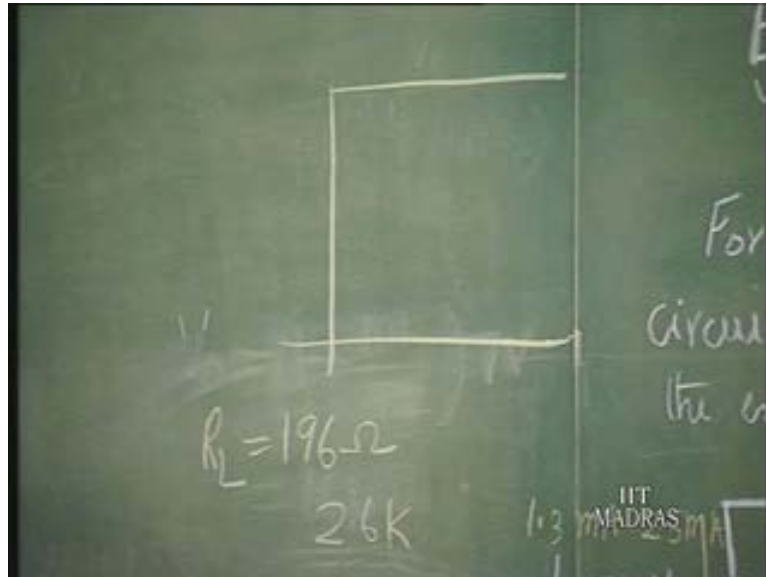


That means we could have done this more easily. A better design would have been to select this R 1 R 2 combination itself as 2 point 6 K. So, there is no question of our...not 2 point 6 K, 2 point 6 K parallel 20 K. Whatever resistance there is. That R 1 plus R 2 itself could be that so that we do not have to worry about this lower limit at all. They can keep it open. That is one way of design; or, you restrict the load resistance to change from 2 point 6 K to 1...196 ohms.

So, load resistance can vary for this particular problem from 196 ohms to 2 point 6 K. Therefore, it starts malfunctioning. So, let us consider that the load under consideration normally is a constant, let us say. Let us discuss other parameters for a constant load. This is the variation of load and we can also plot load regulation by varying only this kind of resistance, because load regulation becomes meaningless beyond this range. Vary the load from 196 ohms to 2 point 6 K and find out how output voltage varies with

respect to this variation of load. So, you can plot that characteristic which will be looking almost as 14 volts constant. This load current is changed from... let us say, corresponding to R_L equal to 196 to...; this is the maximum current, this is the minimum current.

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So this variation, you have to...this may be very small variation that is going to occur primarily. Once again, as the load...if this input voltage is kept constant, this variation is going to be occurring because of the non-idealities of this differential amplifier that you have. That is going to be extremely small. That is, we are assuming that the voltage difference is zero; it is not strictly zero.

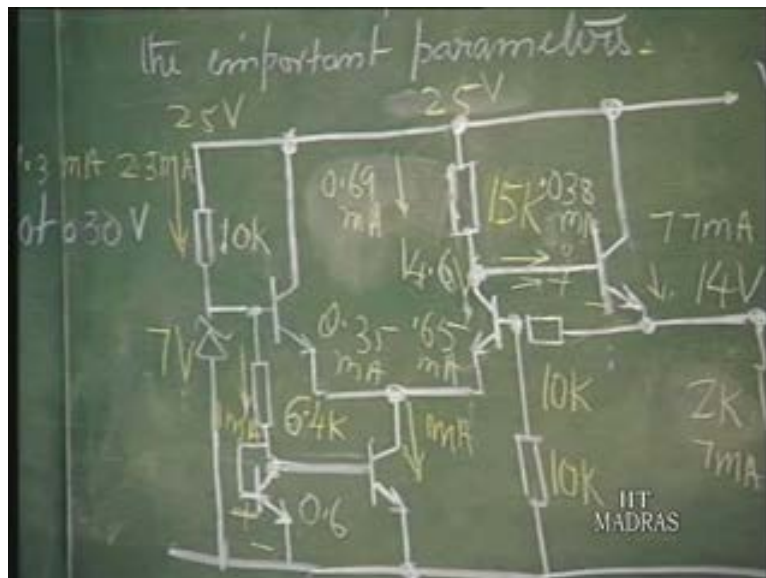
So, the error voltage is zero is what it says. So, the error voltage keeps changing as the load changes because the operating point keeps shifting. So, the error voltage keeps changing and therefore that error voltage variation will appear at the output as the variation in the output voltage. So that, you have to determine experimentally basically because this is a non-linear phenomenon here. Voltage is...the load current is varied over a large range and the operating point keeps shifting and we have to find out how much the error voltage changes.

So based on this, we can obtain the load regulation characteristic. And as far as the other parameters are concerned, like output impedance, this can be evaluated only for a specific load. Let us take the load as, let us say for making matters simple, 14 K. Is it possible? No. We cannot take because we can take it as, let us say 2 K - between 2 point 6 and 196 - 2 K. So, the current here is 7 milliamperes and this is again point 7 milliamperes. So, the total current here is 7 point 7 milliamperes. This is 7 point 7 and therefore the base current is 7 point 7 divided by 200, which is going to be point zero 38. Point zero 38 milliamperes, correct? Point zero 7... point zero 38 milliamperes.

Let us assume that this is nominally fixed at, let us say 25 volts, 25 volts. So, this is fixed at 25 volts. This is 14 point 6. So, this is 25. 25 minus 14 point 6 is the voltage which is 10 point 4. 10 point 4 by 15 K. How much is that? Point 69 milliamperes.

Now for the 25 volts here. This is 14 point 6 volts. The current is point 69, out of which, only point zero 4 volts...let us say, this is point zero 4. So, what is remaining here is point 65. So, this will have point 35 milliamperes.

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So, these will give us an idea about the operating currents of each of these. This is going to be how much? 25 minus 7 - that is 18 by 10 K - 1 point 8 milliamperes. So, these are the operating currents. Now, how do we fix the output impedance? First, let us find out the open loop gain of this structure; open loop gain before feedback.

Feedback factor, Beta in this case is half; 10 K, 10 K. So, R_1 by $R_1 + R_2$ is half; and open loop gain is going to be g_m . Now, g_m is to be evaluated. $r_{e1} + r_{e2}$, 1 over that is g_m . So, v_t divided by i_e ; i_{e1} is point 35, i_{e2} is point 65. So, 25 by point 35. How much is that? 25 by point 35 is 71 point 4; plus 25 by point 65. 25 by point 65 - 38 point 46. So, this is the g_m of the transistor stage. That into r_c by 2, because single...this is the...this thing and this need not be divided by 2 because this is the total resistance.

So, this is the g_m , into R_c . R_c is point 15 K. Of course, please remember that this 2 K is shunted by 20 K. So, 20 K effect can be ignored. So, this load is 2 K and this 2 K will appear here as 2 K into 200. So, 400 K. But compared to 15 K, 400 K also can be ignored. So essentially, it is 15 K. Otherwise, you have to take the loading effect of this into account in evaluating the open loop gain.

So, this is 15 K - R_c . So, that is the open loop gain. This is 15 K by this total, which is point 8 6 9 1 naught 9 - 110, about... So, no... What is the...this thing? Total? 15,000 divided by this thing? That means about 150; 2...136 point 3 6; 136. That is the open loop gain. That into Beta. This is, let us say A naught.

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$$\beta = \frac{1}{2}$$
$$= \frac{R_e}{V_{e1} + v_{e2}}$$
$$= \frac{R_e}{71.4 + 38.46} = \frac{15000}{109.86}$$
$$A_0 = \underline{\underline{136}}$$

So, A naught Beta is going to be half of 136 – 68.

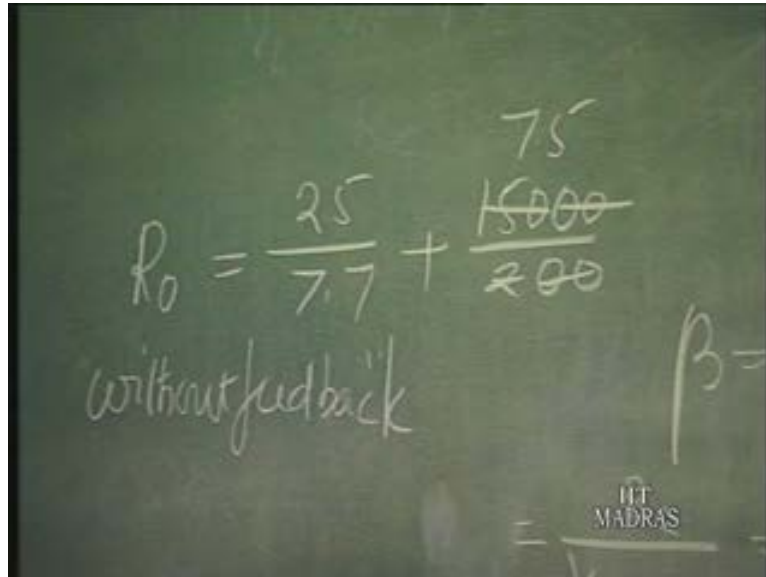
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$$A_0 \beta = \underline{\underline{68}}$$
$$\beta = \frac{1}{2}$$
$$= \frac{R_e}{V_{e1} + v_{e2}}$$
$$= \frac{R_e}{15000}$$

So, the original output impedance is going to be decreased by a factor of 1 plus loop gain. That is what we have learned in our earlier lecture. So, original output impedance is this r_e plus 15 K divided by Beta. Without any feedback, it is simply r_e plus 15 K by Beta, apart from the shunting effect of this.

So essentially, original output impedance without feedback is going to be r_{e1} is 25 by 7 point 7 ohms plus 15 K divided by 200. So, you can notice that it is essentially 75 ohms plus about 3 ohms; 25 by 8 - about 3 ohms. That means 78 ohms.

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The image shows a chalkboard with the following handwritten text:

$$R_o = \frac{25}{7.7} + \frac{15000}{200}$$

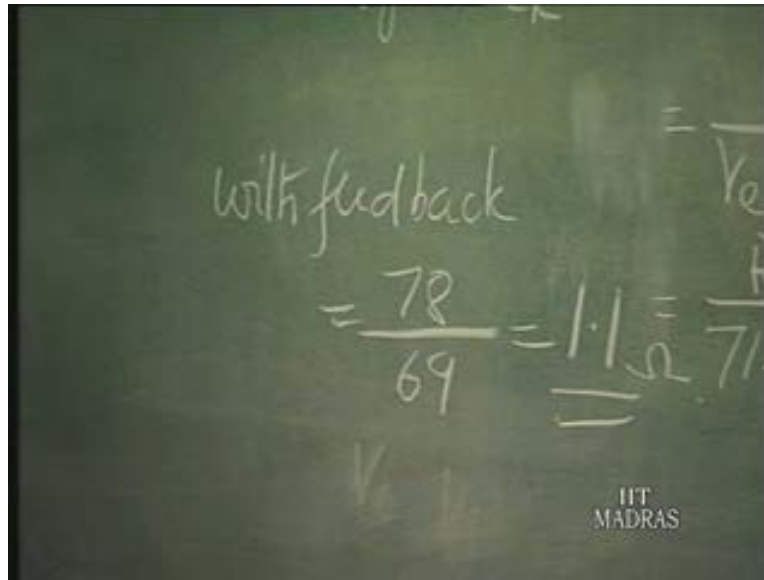
without feedback

$\beta =$

ITT
MADRAS

So, this has to be divided by with feedback, 78 divided by 69 ohms. How much is this? Very nearly 1 ohm; and that is the output. 1 point 1. So, this is the kind of output impedance of the structure.

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I think that you have to remember is this is a feedback structure; and that is why it is giving pretty low output impedance. If you use an op-amp, it can become fractions of ohms; but that is valid only for low frequencies. At high frequencies, we cannot assume this kind of gain. Loop gain reduces and output impedance increases. This has to be borne in mind because this regulator may be used for high frequency application.

So, output impedance is important only for high frequencies. Low frequency output impedance is of no significance. So, how much the circuit that is being supplied...this power is...loop seeing. That impedance becomes important only at the frequency at which the circuit is functioning. This is functioning at low frequency. This is a D C regulator and therefore output impedance on the other hand is important only looking at the circuit from the circuit that is using this as a power supply.

So, that circuit may be work...working as an oscillator at, let us say 1 megahertz. Then, you have to evaluate the output impedance at 1 megahertz for this circuit. So, that may not be purely resistive. So, that output impedance may become pretty high and it may cause problem, unless you purposely reduce it using special technique.

Like now, this, if it does not use an op-amp, the output impedance at low frequency will be almost same as output impedance at high frequency. The moment you use an op-amp, that gets drastically changed. So, output impedance is evaluated. You can also evaluate the repel rejection by replacing the whole by its equivalent circuit and varying this voltage by a small extent and finding out what this voltage is; or, most of the repel rejection occurs because of this. The...when there is a repel, there is a transfer here which is going to be R_z divided by $R_z + 10\text{ K}$; that will be simply multiplied by a factor of 2. So, the repel rejection is going to be due to this fact that R_z by $R_z + 10\text{ K}$ into 2 is the repel rejection factor expressed as a percentage is really what is normally indicated as repel rejection.

So, these are the important parameters associated with this. Apart from that, we can also find out the efficiency. Efficiency here is essentially 14 by 25. I have told you that it is just ratio of output voltage by input voltage; 14 by 25 is the efficiency of this.