Electronics for Analog Signal Processing - II

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Lecture - 30
Analog Multipliers
(Modems & Mixers)

We had so far discussed primarily linear operations like multiplication by a constant, subtraction, addition and an integration, differentiation; all these are linear operations. For example, filters where solving a linear differential equation...oscillators also. So now, we are going to discuss about non-linear operations.

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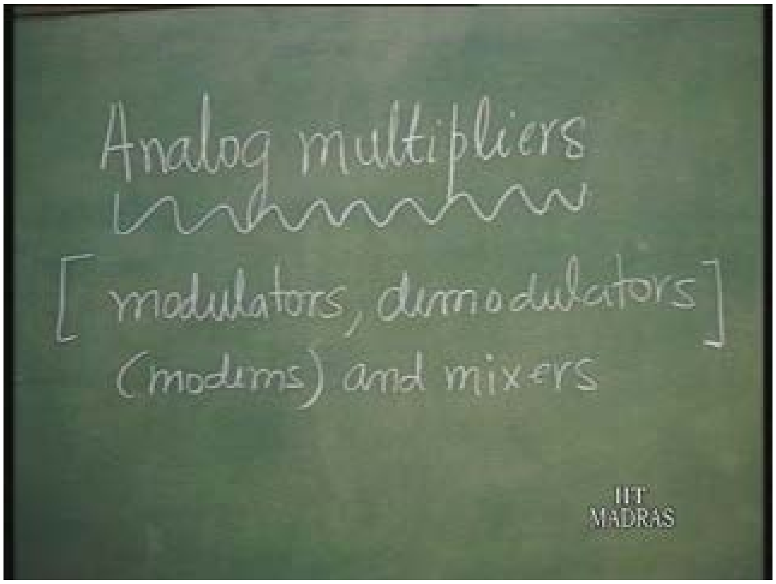

Analog multipliers

[modulators, demodulators]
(modems) and mixers

So, in this, the most important block is what is called as analog multiplier. Multiplier here means I am multiplying two currents or two voltages. It is not multiplication by a constant, which was the linear operation we discussed as amplifier or attenuator, earlier. Here, here it simply means multiplication by two voltages or currents.

Strictly speaking, multiplication operation as defined by an ideal device indicating that it is multiplier, it has two inputs: one input will be having, let us say V x as its input and another, let us say V y; output V naught. This is the symbol for the multiplier.

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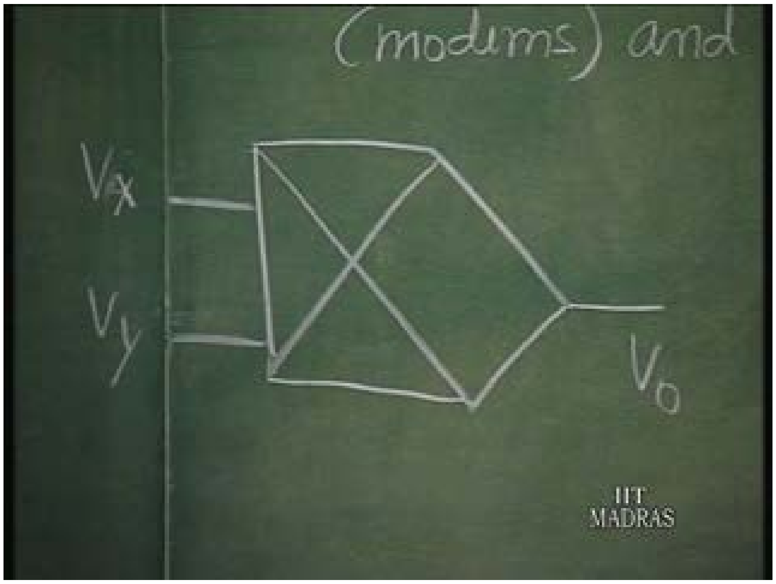

So, V naught is going to be equal to a function of normally two inputs now, V x and V y, normally. For anything, any device put here, it is going to be a function of V x and V y.

How will it be? Normally, it is going to be equal to a factor which is independent of V x and V y. That we call as voltage, which is an offset voltage, is independent of V x and V y. This, we call as an offset. Same thing is true with amplifiers also. In the case of an amplifier, it is a function of only one input because there is just one input - V x. So, output is a function of only one input, V x; but then it could be independent of V x which is also called offset there.

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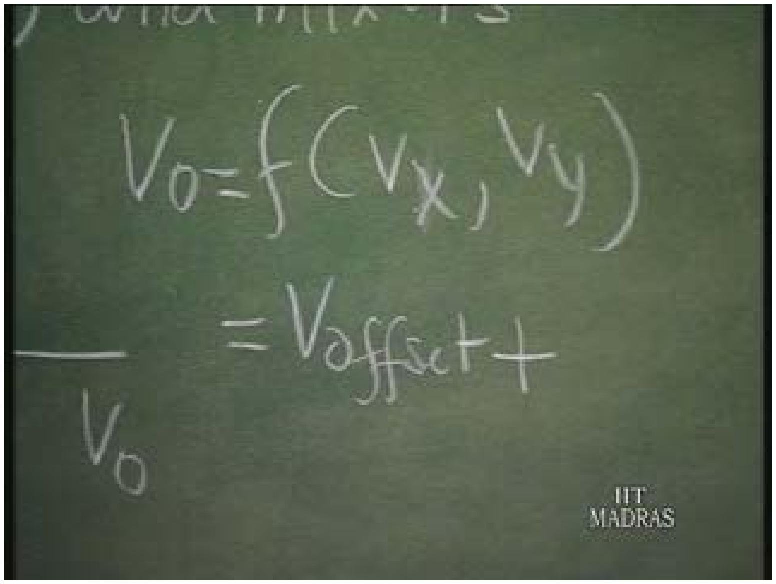

So V offset. Then, plus... In general, we can have what is called K x which is an output only due to V x. In the case of an amplifier, this is important; and it will be also similarly dependent upon V y. These are all linear terms which might exist, in general.

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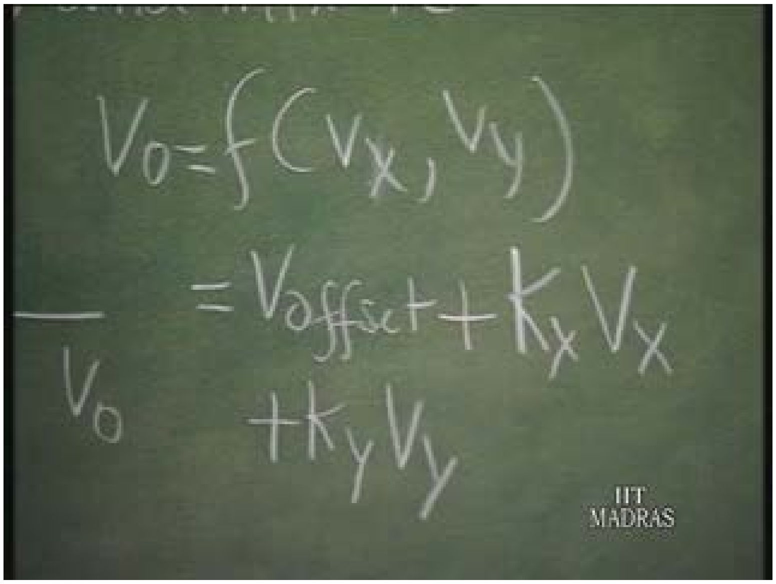

These are called...in this case of multiplier, these are called unwanted terminal terms. These are called feed through: x feed through and y feed through component. This is x feed through component. This is y feed through component. This should not occur in a multiplier. In an amplifier, these are things which are supposed to be available.

Next, we have K naught into V x into V y. This is the product term which we want. Then, terms which will be dependent upon V x squared, V y squared, V x squared into V y, V y squared into V x, these are all called non-linear terms in multiplier. Further non-linearity.

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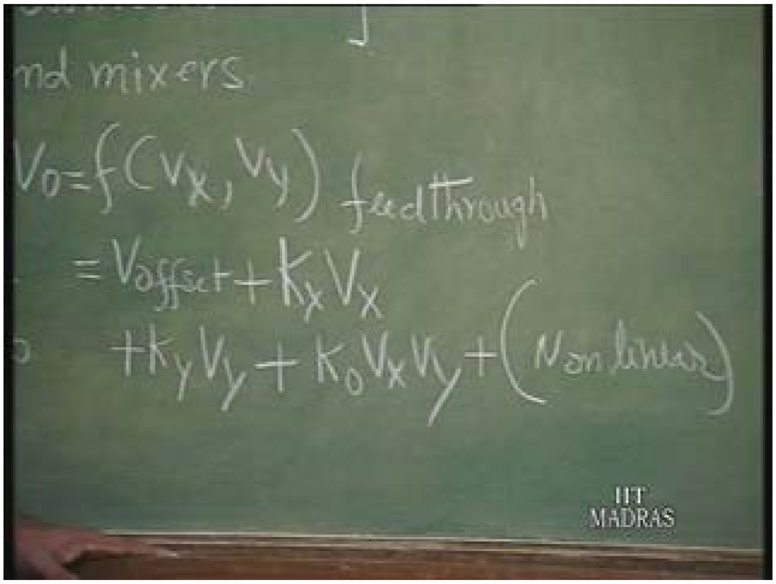

Please understand that this itself is a non-linearity which is being exploited here. These are the linear terms. These are independent of the input.

So, in any non-linear device, you can get all these terms. If it is going to be a good multiplier, you have to select the configuration in such a manner that only this exists. K x is zero, K y is zero, offset is zero and this also should go to zero. That means the choice of the configuration should be such that these are going to zero, automatically. And that configuration is ideally suited for multiplication. So, we will see what is the configuration that will give that.

Then, K naught is obviously equal to 1 over some V reference. It is...in order that output is a voltage, you are having product here. So, this should be 1 over voltage. So, it is a dimension of 1 over some V reference; and in a standard multiplier, this has been made equal to 10 volts.

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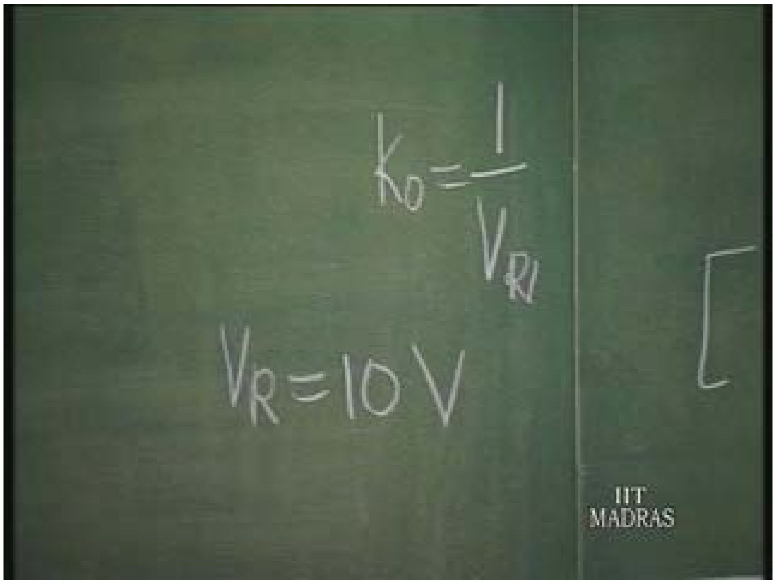

In a precision multiplier, available as I C multiplier, this V reference has been chosen as 10 volts so that V x and V y, the dynamic range within which this is going to operate, will also be restricted to 10 volts.

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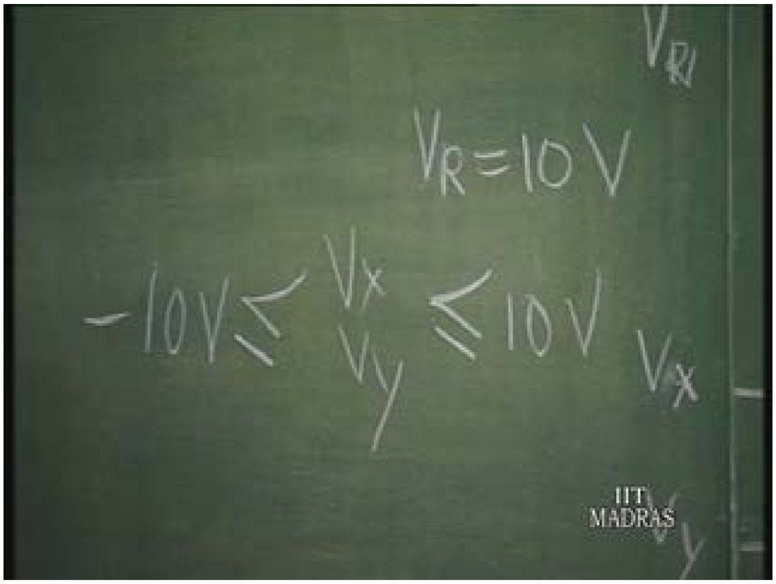

That means, if V x is 10 volts, V y is 10 volts, V naught is going to be 10 volts, if you select V r as 10 volts. So, that means this multiplier is compatible with another multiplier which is having the same dynamic range. So, we can couple these multipliers without any difficulty and have no problem about dynamic range of such things. That is why this has been standardized.

So, in an I C multiplier therefore, V r is 10 volts. In other types of multipliers which we are going to use for communications, V r can be any value, depending upon your application. So, this is a precision multiplier, I C multiplier, which is going to be usable over the widest voltage range; and such I C multipliers are available for about 1 megahertz or so, operation.

Now, let us therefore think of ways and means of designing multipliers and then see how these multipliers can be used for a variety of applications like modulators, demodulators. These are all communication circuits, mixers; and these are also called... Modulator, demodulator, is also called modem which is one of the important unit these days for computer communication.

So, we must learn about how such modulations and demodulations occur in any system. Now, this also forms an important unit in what is called phase detector; then, phase lock loop. So, the applications of these are enormous: phase detector, PLL, phase lock loop - all these things require the use of a multiplier.

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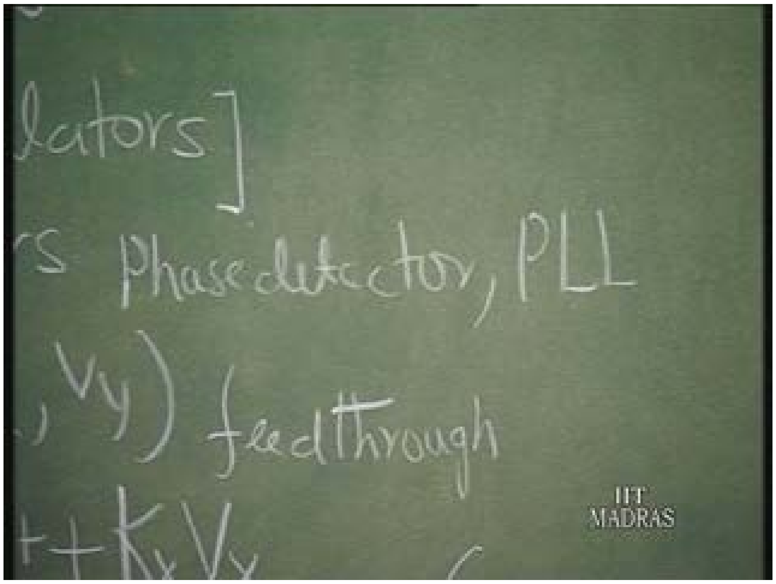

Therefore, let us understand first how multiplication is done by selecting a proper configuration, then go over to a discussion of applications in all these areas.

As far as the multiplier I mentioned about is concerned, the I C multiplier, there are four adjustments to be made before using it. First is to make the offset equal to zero by making V x equal to zero and V y equal to zero. So, you make V x equal to zero and V y equal to zero. Then, make the offset go to zero. That is called offset adjustment. This is the first adjustment.

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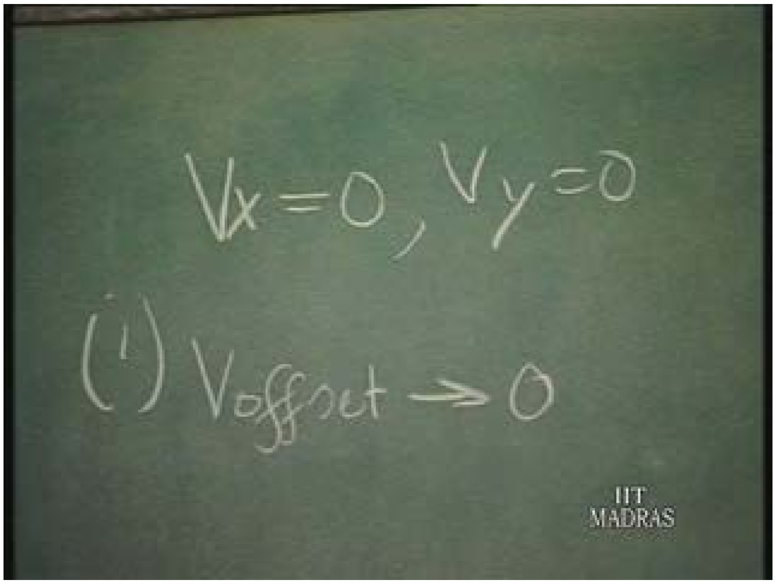

$V_x = 0, V_y = 0$

(1) $V_{offset} \rightarrow 0$

Then, make V x equal to 10 volts. Make V y equal to zero. After this adjustment is made, already offset has gone to zero. So, now you make V x equal to 10 volts and V y equal to zero volts. Then, adjust K x. That is, the feed through component of x. It is only because of existence of K x that V x will come. So, this go to zero.

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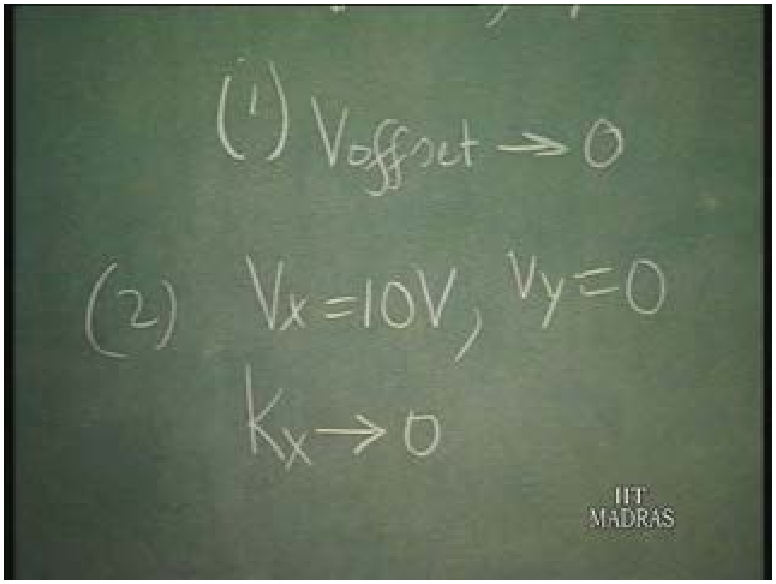

(1) $V_{offset} \rightarrow 0$

(2) $V_x = 10V, V_y = 0$

$K_x \rightarrow 0$

Then, the third adjustment is obviously V y is equal to 10 volts and V x equal to zero volts; and make... Now, only thing that can come out is K y or y feed through component. This is going to be adjusted to zero; and finally make V x equal to 10 volts, V y equal to 10 volts and make V naught equal to...go to 10 volts.

Keep V x equal to 10 volts and V y equals to 10 volts and adjust such that V naught goes to 10 volts. That means then, V r would have become 10 volts. By making this adjustment so that V naught is maintained at 10 volts, V r would have automatically been adjusted to 10 volts.

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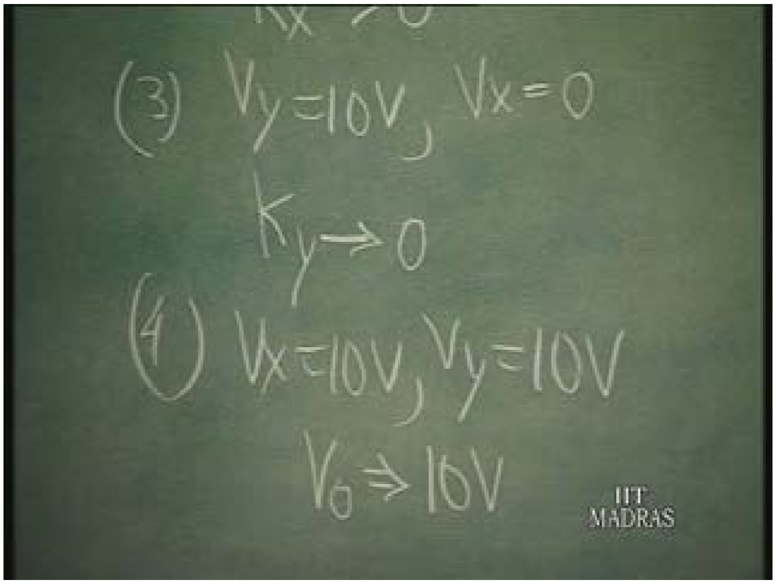

$K_x \rightarrow 0$

(3) $V_y = 10V, V_x = 0$

$K_y \rightarrow 0$

(4) $V_x = 10V, V_y = 10V$

$V_0 \Rightarrow 10V$

So, these are the four adjustments that have to be made in the case of a precision multiplier before it is ready, and we can say that V naught therefore is going to be equal to V x V y by 10. So, once you say that, thereafter, you do not have to keep telling that this multiplier is usable for a dynamic range of V x V y less than 10 volts, greater than minus 10 volts. All these things are understood.

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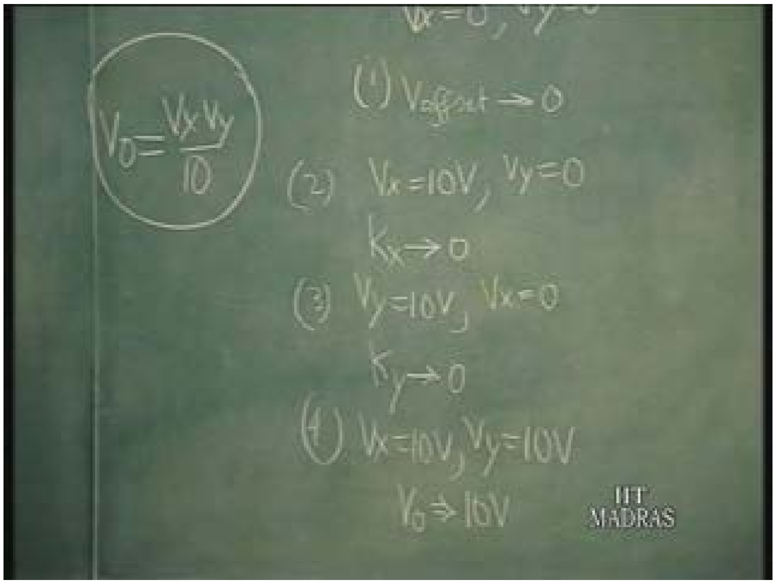

So, if I now put that symbol for the I C multiplier, I do not have to say that input and output are limited to 10 volts. It is taken for granted; but these four adjustments have to be made before this can be concluded. So, what is really a multiplier? Strictly speaking, we can understand multiplication from our old usage of log-antilog tables.

We used to perform multiplication during those old days. The present generation people are not aware of log-antilog multipliers because of the advent of calculators. But in the olden days, log-antilog multipliers were part and parcel of every engineer, for calculation purpose. That is, logarithm amplifier is necessary for multiplication. That is one method of multiplication.

So, we will first discuss the good old ways of multiplication by taking log of a voltage and adding it with log of another voltage. So, I just take log of V x and add it to that, log of V y; and then obviously, it is V x V y by another voltage 10. So, add this and subtract log of 10 and then take antilog. I should therefore get V x V y by 10. This is as simple as that. That means I take log of V x and take log of V y and add them together and subtract log of 10 and then take antilog. Then I get V x V y by 10.

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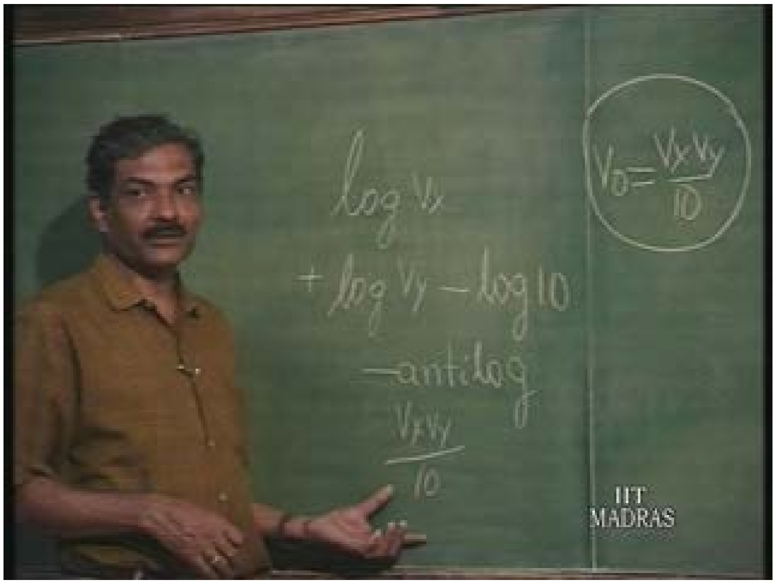

Now, when I do this design, I can also design a divider. Please remember. I can take log of V x and log of V r and subtract log of V y. So then, I will get V x 10 by V r. So simultaneously therefore, I can design a multiplier dash divider.

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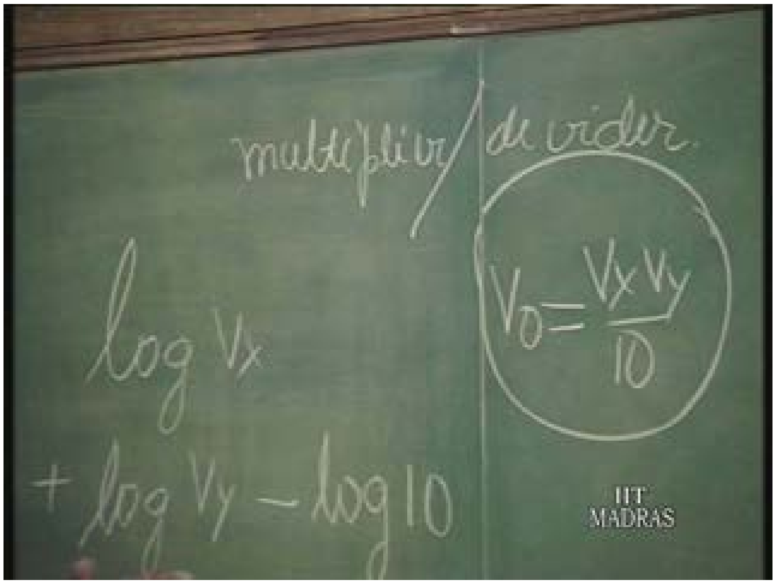

Only thing is the input...these things will be varying. That is, this is V x, this is 10 and that is V r...y. Then it becomes V x 10 by V r...V y.

So therefore, in this case of log-antilog multiplier, this is called log-antilog multiplier, the basic principle of this is just this. So, in order to understand this, in fact all these things are not log to the base 10, they are natural logs; so, natural antilog.

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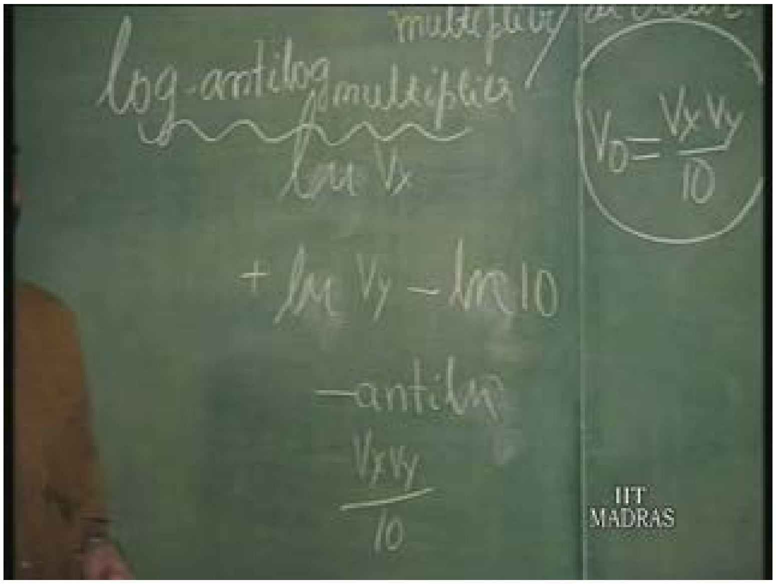

But, it is always termed as log-antilog. Now, let us see how therefore log amplifiers are built.

So now, we are going to discuss an important design factor called log amplifier. We have to understand how to take the logarithm of a voltage. This is a non-linear operation. This itself is a non-linear operation. This is also called an important communication building block. When you take a logarithm of something, you are actually compressing the entire thing because you consider log of 10 is 1, log of 100 is 2, log of 1000 is 3.

So, you are compressing the information in a very short range. So, this is called a compandor. Again, this is an important unit of communication. You want to compress some voltage or current. Therefore, you can use this particular unit, log amplifier. So, that log amplifier forms part of a unit called multiplier. So, it is better to understand first this basic unit called log amplifier; how to build a log amplifier.

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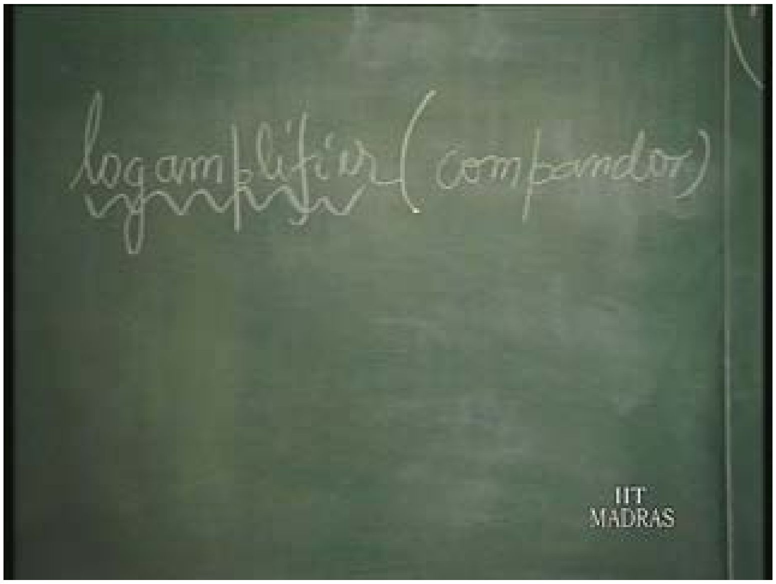

This can be very easily built by using a very important component that we have discussed earlier; that is a diode. In the case of a diode that we have discussed long ago, we know that the voltage and current relationship, semiconductor diode, is logarithmic.

That means the current in this diode, forward current, when it is forward biased, that i d is equal to I naught exponent V diode by V T minus 1. This is known to you; V T being equal to 25 millivolts at room temperature.

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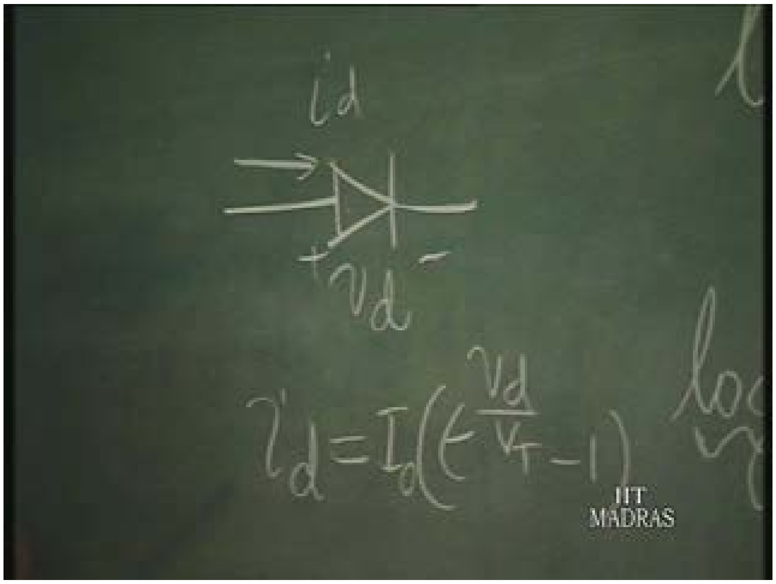

This is approximately equal to...if it is remaining in forward exponent V diode by V T, because its characteristic only in the forward bias region is going to be exploited for logarithmic operation. For therefore current switch, this I naught may be of the order of picoamperes or so. So, this under normal bias conditions is going to be something like this, approximation.

So, if this is the case, V diode therefore equals V T log I diode by I naught, from this. That means this is the log operation. This...this is the log operation of the current and this is the antilog operation of that.

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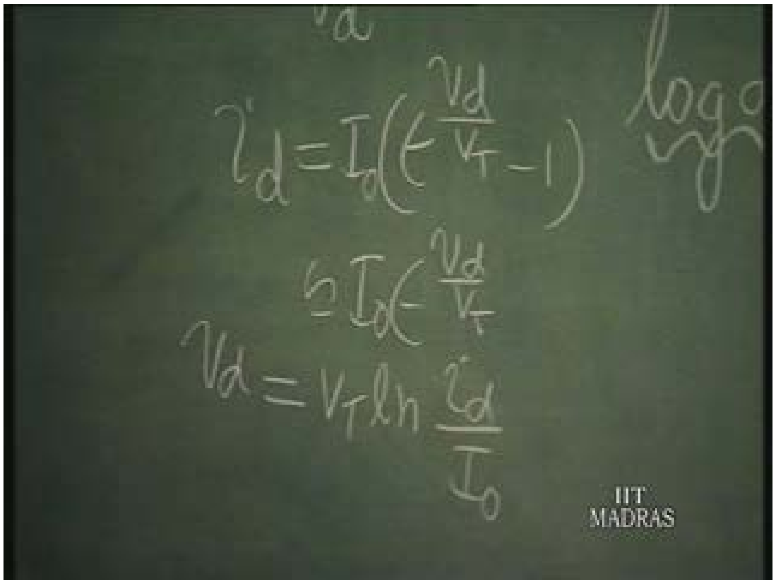

So, by using this current and voltage interchangeably, we can perform both log and antilog operation. How do we therefore convert this into voltage voltage operation?

So, I know that the current, if it is made to depend upon a voltage, this will be output voltage of the diode. It is going to be V T log voltage by something. So, I have to make this current become depend upon a voltage. That can be easily done by putting this diode in the feedback loop of an op-amp.

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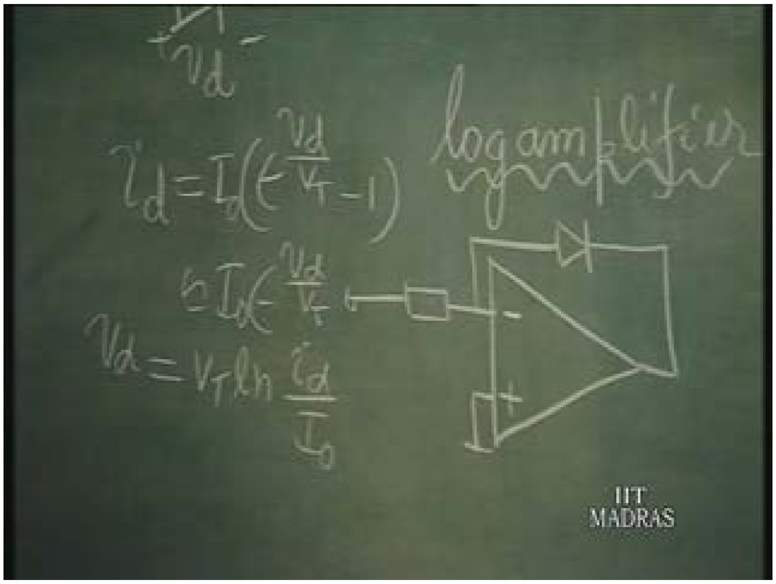

We know that this op-amp, if it is now connected in the feedback loop like this...and we take this output voltage V naught...this should always remain forward biased. That means, the current in this direction should keep flowing because that current alone can keep the diode in the forward bias mode. So, what is the current here? If this is V i, and if V i is greater than zero, then only the current direction is going to be this.

So, this is a log amplifier only for positive voltages. So here therefore, please remember that V i is restricted in its polarity. It cannot be changed. So here, it should be always positive. So, if I have a resistance R here, the current in this which will forward bias the diode will be in this direction, if V i is greater than zero. Then the current in this is V i by R, which is going to forward bias the diode; and therefore, the voltage across the diode is going to be the output. It will be plus and here minus here; therefore, it is minus V diode; which is minus V T log...

What is I diode? V i by R. So, V i divided by R I naught. So, this is what is called a log amplifier, strictly speaking; a very simple structure, where I have exploited the property of the diode where voltage and current are logarithmically related; and then put the op-amp here to convert the voltage into current; and made the current pass through the diode in the forward direction; and developed a voltage across the diode which became the output voltage. Is this understood?

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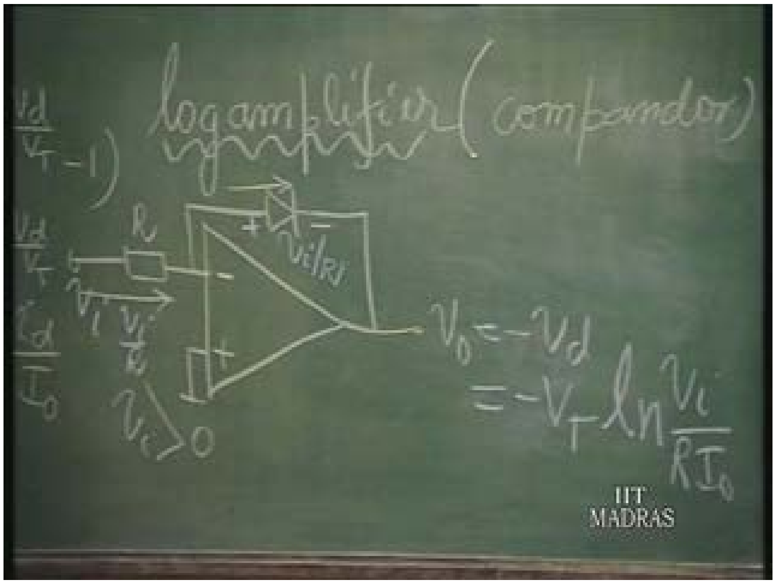

Now, the same thing can be done using a transistor also. So, what do we do? The emitter base junction of a transistor is similar to that of a diode. That we know. So, suppose we have a transistor instead of a diode. This is going to be forward biased; and if this current is I E naught, I E, I E is going to be I E naught. I E is going to be I E naught exponent V B E by V T, approximately equal to, when it is forward biased. So, instead of a diode, I can use a transistor connected as a diode. Let us see.

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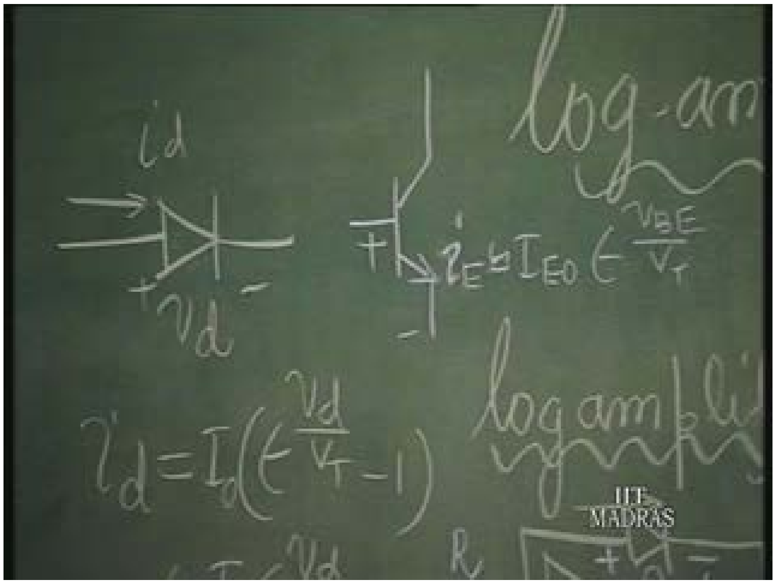

So, we know that when the base to collector junction of a diode is shorted like this, it acts as a diode. This, we have used in the current mirror also; base to junction is shorted; it is being used as a diode which is forward biased in this direction. So, this is a transistor connected as a diode. There is no difference between this and a diode as far as the terminal characteristics are concerned. Now, what is the collector to base voltage here? Zero, because I have shorted it.

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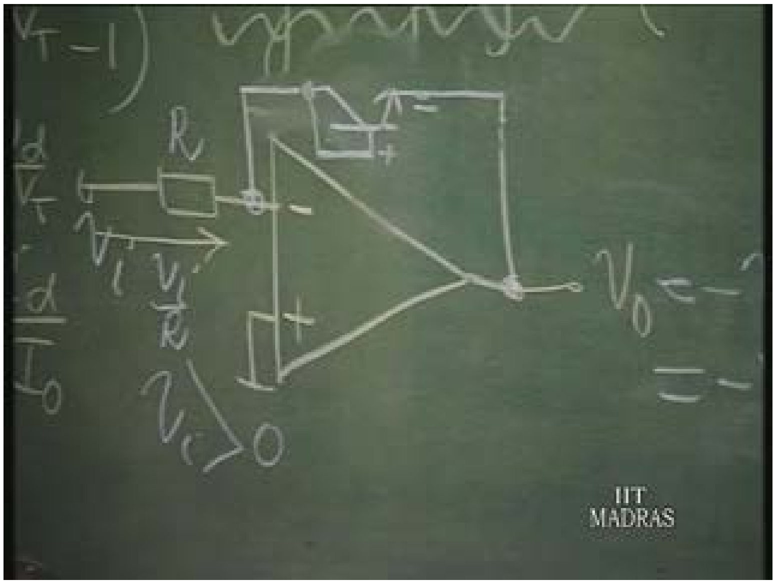

Instead, I can remove this and also connect it to ground. Now, what is the voltage here? It is still zero because this is ground potential and this is virtual ground potential, because of the op-amp. So, whether it is physically shorted or connected in this manner, the transistor is still acting at V c b equal to zero.

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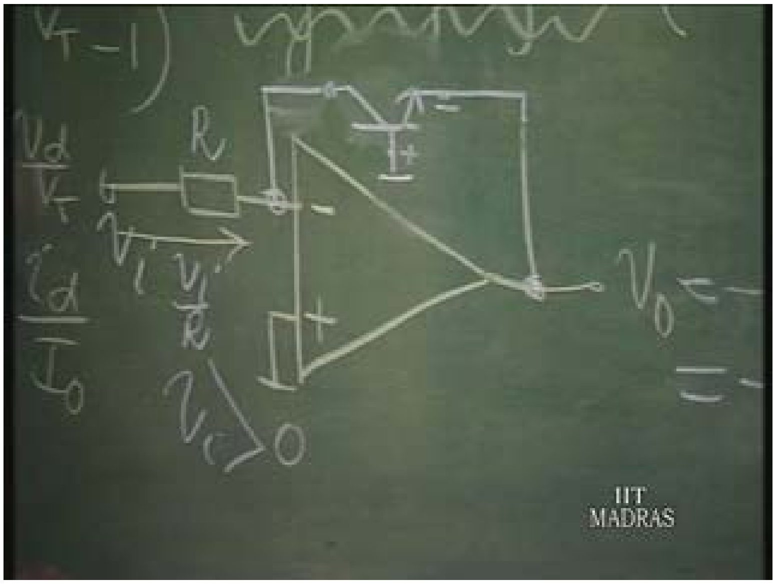

With V c b equal to zero, we had that diode connection. But now, this is acting as a transistor, please remember, with V c b equal to zero. What does it mean? When I inject a current of V i by R in order that this is to remain as virtual ground, this current should become equal to V i by R. That will happen by...base to emitter voltage now from ground to this point getting generated as equal to minus V T log V i by R into I naught. So, that means this automatically develops an output voltage because of the negative feedback such as to pass this current in the collector. So, this is a log amplifier using a transistor in place of the diode.

So, as far as the output voltage is concerned, it still remains the same thing. Only thing is, instead of I naught, we will now put I E naught. So, this is the difference between a transistor and a diode connection.

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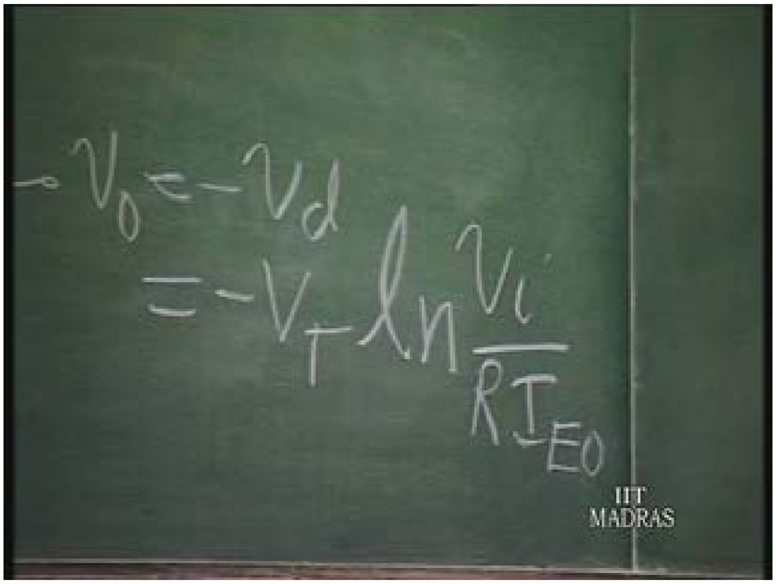

$$V_0 = -v_d = -V_T \ln \frac{v_i}{R I_{E0}}$$

Now we are bothered about this fact that V naught is equal to now, you can see here. V T which is K T over q; that is a temperature dependent factor here. And I E naught also is very severely dependent upon temperature. It doubles for every 10 degree rise in temperature. We have said this is a leakage current of a diode; reverse saturation current it is called. This doubles for every 10 degree rise in temperature. So, this is no use as an amplifier if I do not compensate for this variation as well as this variation.

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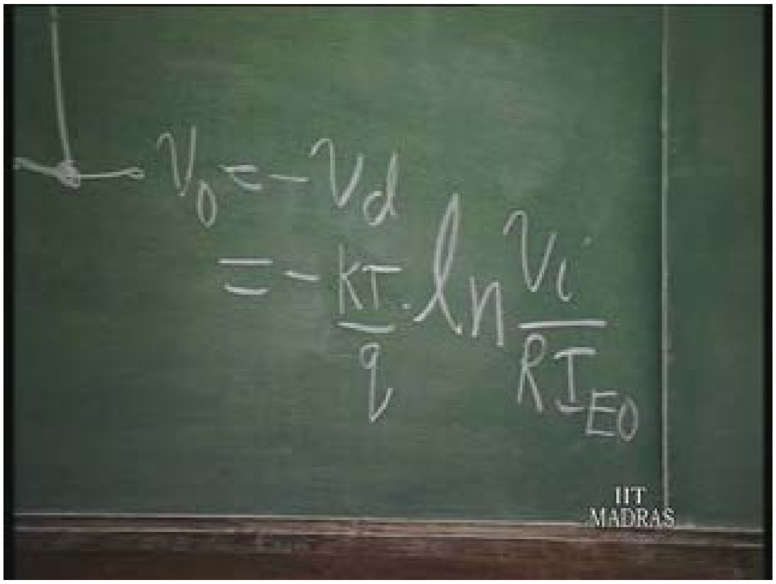

$$V_0 = -v_d = -\frac{KT}{q} \ln \frac{v_i}{R I_{E0}}$$

So, if I want to use this as a compandor, or use it as a log amplifier, I have to compensate for temperature variation here as well as here. Now, this temperature variation is a well-known thing. Why? This temperature coefficient of V T is K over q. It is constant. So, I can design a circuit using resistive network such as to exactly get the same temperature coefficient for that resistive network but in the opposite direction.

So, this particular thing can be compensated for by simply introducing an attenuator. Let us therefore discuss how this log amplifier can be designed with proper compensation for V T and proper compensation for I E naught. So, as far as V T is concerned, I can design an attenuator. How do I do that?

What I do is I simply say, this is going to be V i; this is going to be V i by R. This is the collector current and this shall be the voltage. But after this, I will put an amplifier. So, this voltage V naught here is going to be this voltage, which is minus K T over q log V i by R i naught, into this gain, which is, let us say R 1 and R 2. So, 1 plus R 2 by R 1 into K T over q, minus of course, log V i by... So, this is the output voltage at that point.

Now, by putting a thermistor in this R 1 R 2 network, I can get over the required range of variation of temperature. This linear variation can be compensated so that this entire thing can be made temperature independent. So, this whole thing is made temperature independent. These are standard networks. The thermistor compensated networks are available; how to compensate for this kind of variation of temperature by using current... So, these designs are already available.

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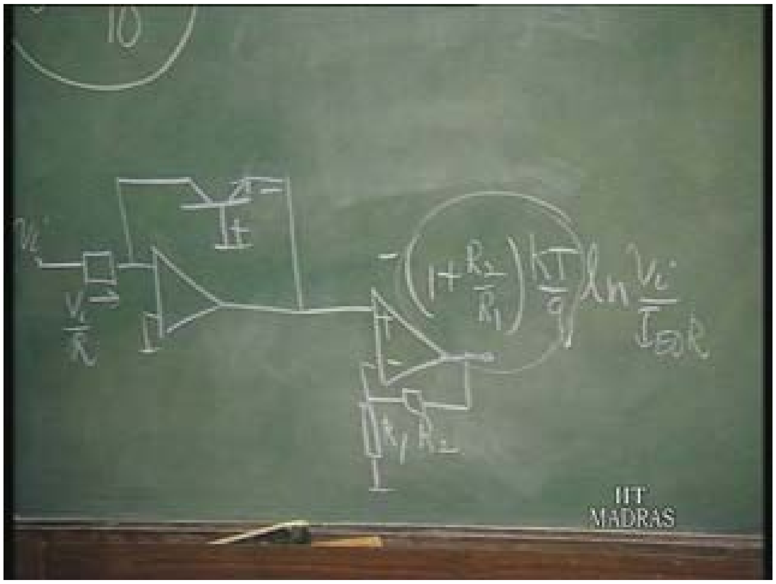

So, this part is something that can be temperature compensated. Then, how do we compensate for this? I E naught variation in temperature is not all that clearly known. So, what is done here is why not add... This is minus something; add another voltage in series with this so that this is going to have plus here itself.

I will therefore add a voltage here. Please remember. Plus K T over q. This is a minus K T over q. I will put plus K T over q, log V R by I E naught into R. So, I am adding another voltage. How do I add voltage?

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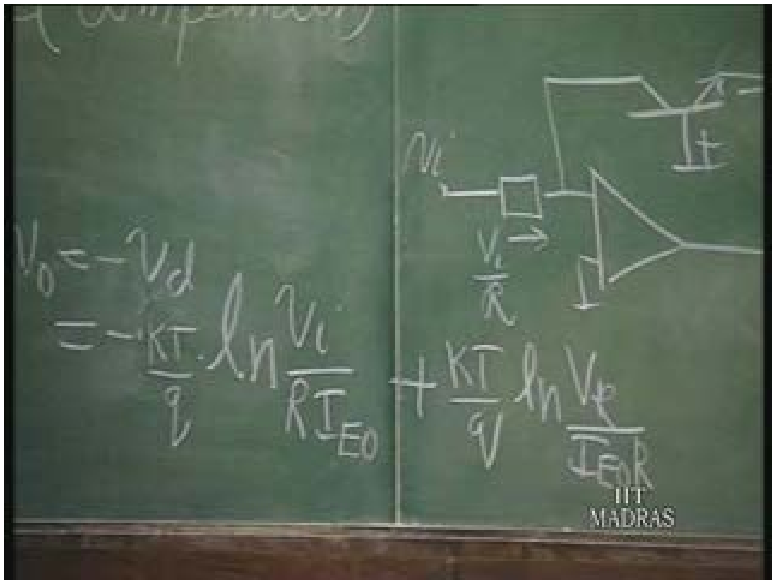

This is nothing but voltage of a diode whose current is V R by R; voltage, forward voltage of a diode whose current is V R by R. Just like we had... Only thing is it is a constant current now. So, if I add another voltage, how do I add this voltage? This is plus, minus. So, I will have to add a voltage which is going to be in this direction, diode potential. So, this will be plus and that will be minus. So, this is plus, minus. This will be minus, plus. So, that means, this is negative and this is positive voltage here, added.

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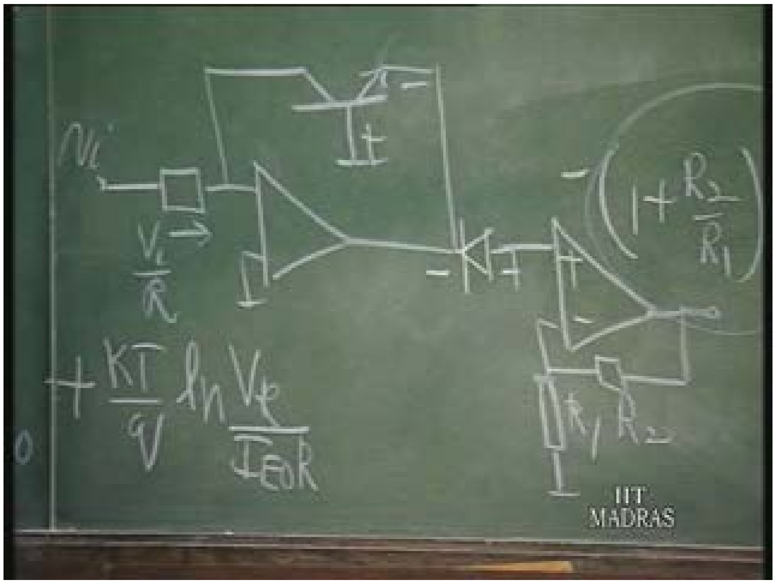

If I do that, what will happen to this voltage now? This will become, whole thing will become multiplied by 1 plus R 2 R 1. This into log V i by I E naught R minus log V R by I E naught R.

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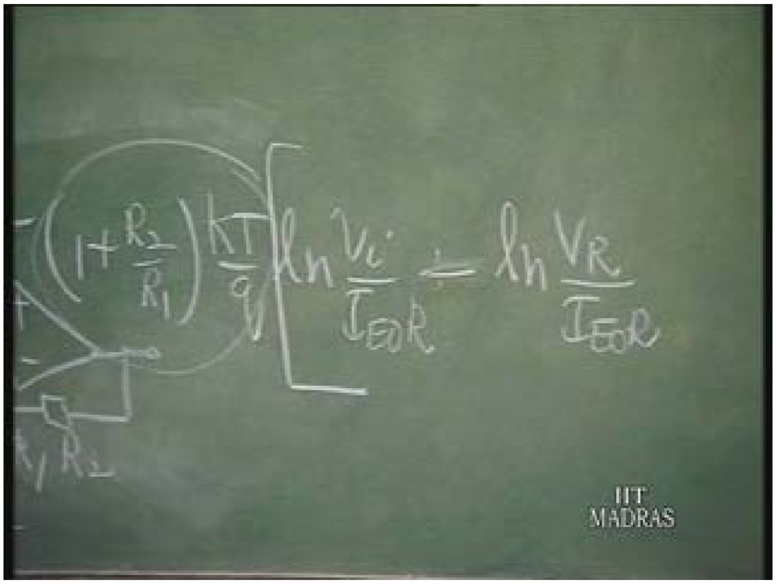

This is a constant current, V R by R; we will call it as...instead of...both are constant current I R. So, what happens to this now?

This becomes log of...log x minus log y, log x by y; and it becomes independent of I E into R. So, this whole thing becomes logarithm of V i by I R R. I E naught gets cancelled. This is the way to compensate for the effect of I E naught using matched transistors in this case.

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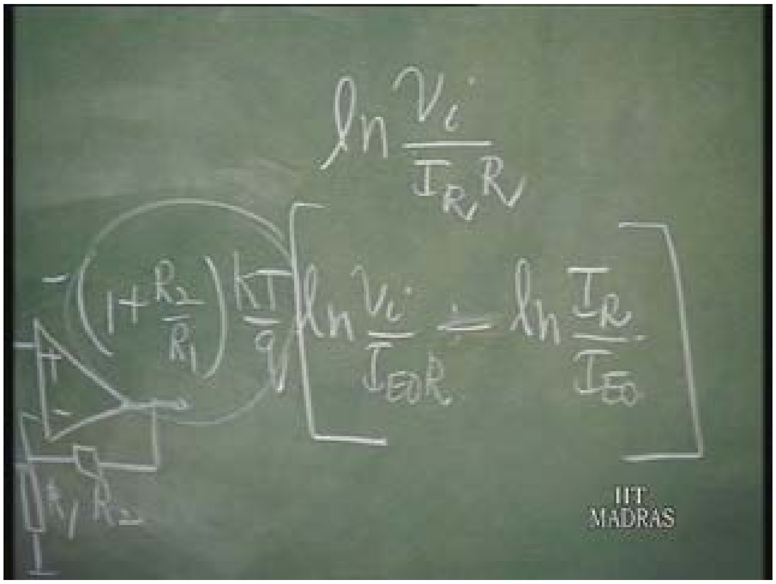

That means, this particular transistor again has to be connected as a diode here. So, it will be something like this. Let us say, it is connected as a diode and I had to pump in current into this so as to forward bias this by a current source which is going to be carrying a current of I R.

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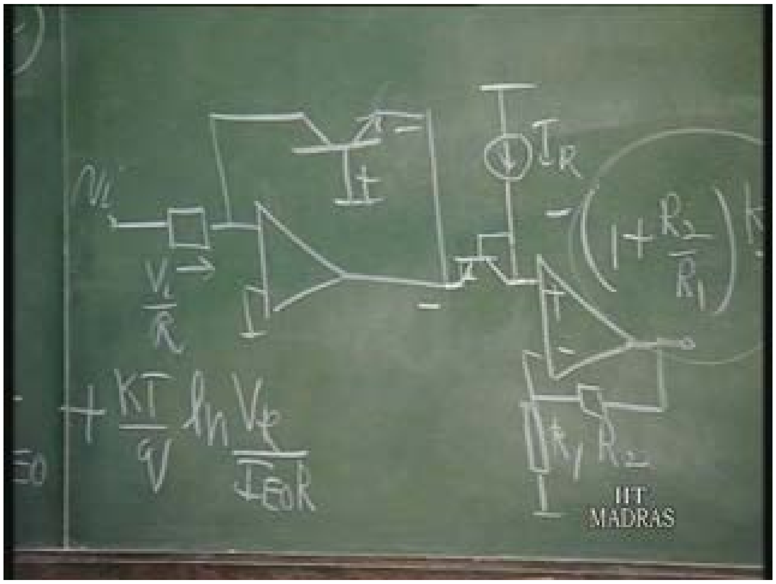

So, you can see that this is the way I will compensate for I E naught. That means the whole thing now is going to boil down to a nice logarithmic amplifier where it is going to be independent of temperature variation.

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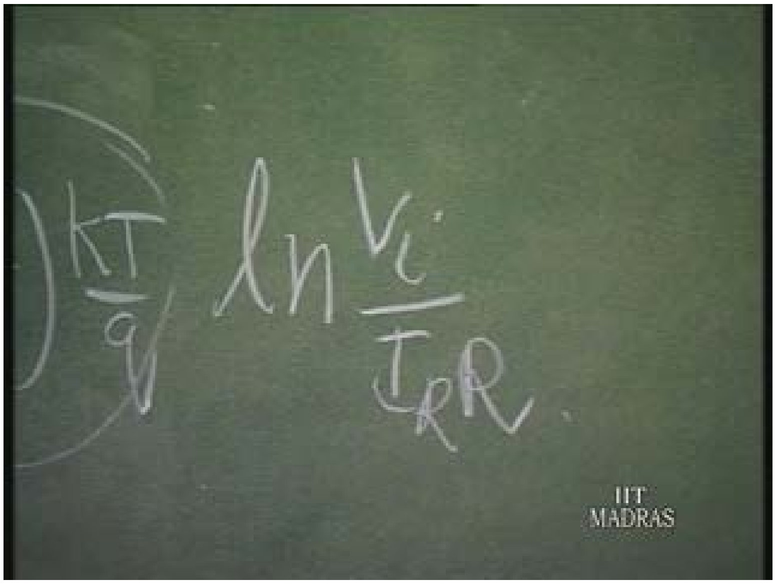

This has already been compensated for temperature. This gets now compensated. This is what is called a temperature compensated log amplifier. The circuit is this full circuit.

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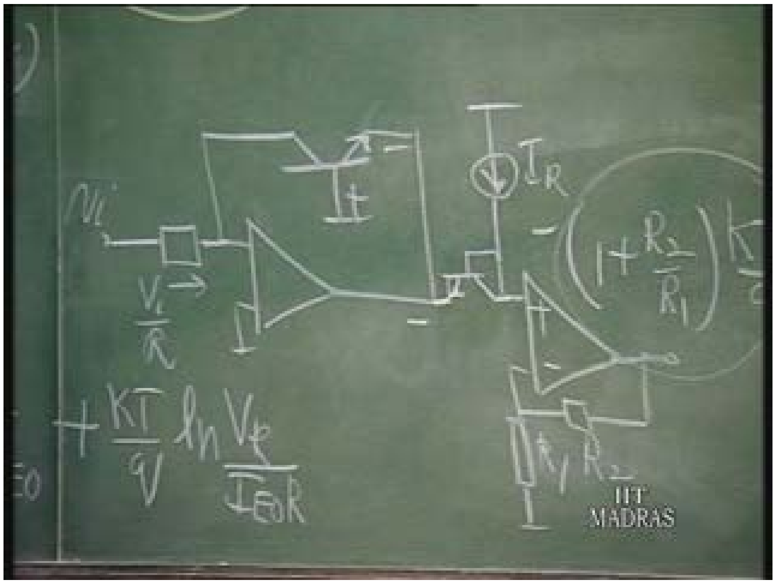

Now that we have understood how to design a log amplifier...we have not yet gone for multipliers; we will discuss that later. That kind of compensation may not be needed when we design a multiplier. That is a different matter. Multiplier is a block which will use a large number of such log amplifiers; and then use an antilog amplifier.

First therefore, we will understand how to design a good log amplifier; then how to design a good antilog amplifier; then see whether such compensation is necessary at all for multiplier because log operation and antilog operation, when you are doing automatically, they may get compensated. So, there is no need for providing separate compensation in a multiplier. So, we will now discuss a good antilog amplifier design.

We have discussed log amplifiers. Now we will discuss antilog amplifier. Log amplifier was data compressor or compandor. Now we will discuss data expandor. So, after compression and processing the signal, we would like to expand in the same manner. This is one of the coding techniques.

So, antilog amplifier. So, what is antilog operation? It is enough if we now interchange the position of the diode and the resistor in the op-amp set up; it is always the case. If you perform, let us say squaring using op-amp in one manner, the square rooting can be done by merely interchanging the element that has been used for squaring, and the resistor.

So, if this is V i, the diode voltage has been forced to be equal to V i because this is ground, this is virtual ground. So now, you are forcing V i to be the diode voltage. So, diode voltage is equal to V i. That means current in the diode is equal to V T log... That is actually, current in the diode is equal to I E naught exponent...V diode divided by V T, which is V i by V T. This is the antilog operation.

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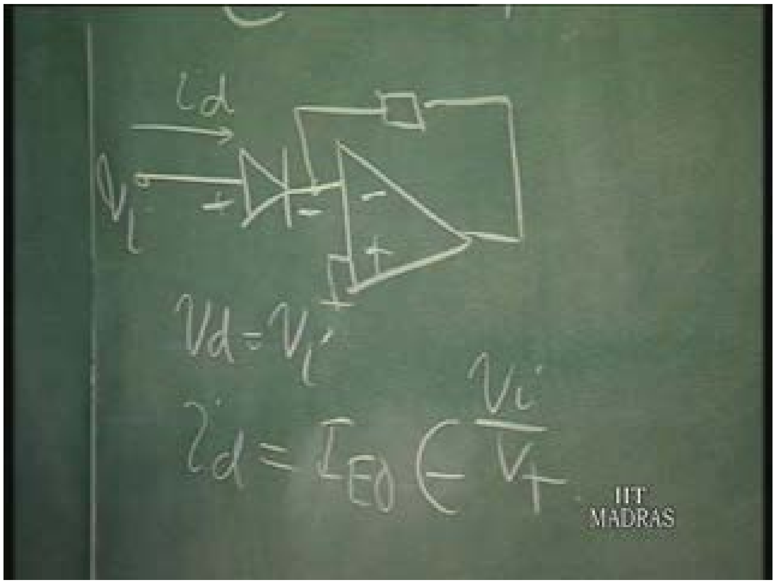

If V i is V T log something, this will become antilog. So, this is the antilog operation. Say, this current, when it is forced into a resistance R, will develop a voltage which is I d into R. So, V naught is equal to minus I d into R. This is plus, that is minus. So, we get this as minus R I E naught exponent V i by V T. This is the antilog operation or this is the data expandor.

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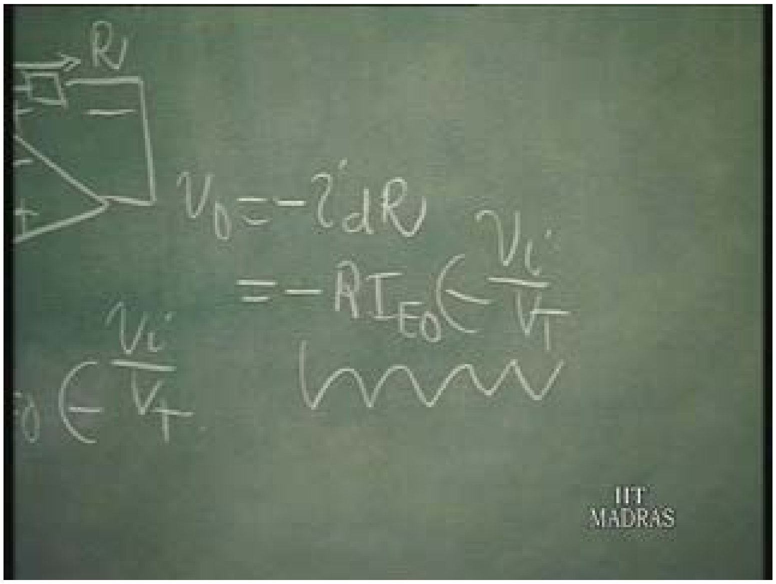

Now, this also is temperature dependent. You see, I E naught is dependent upon temperature; doubles every 10 degree rise in temperature. And this is also temperature dependent, because of this factor, K T over q coming into picture.

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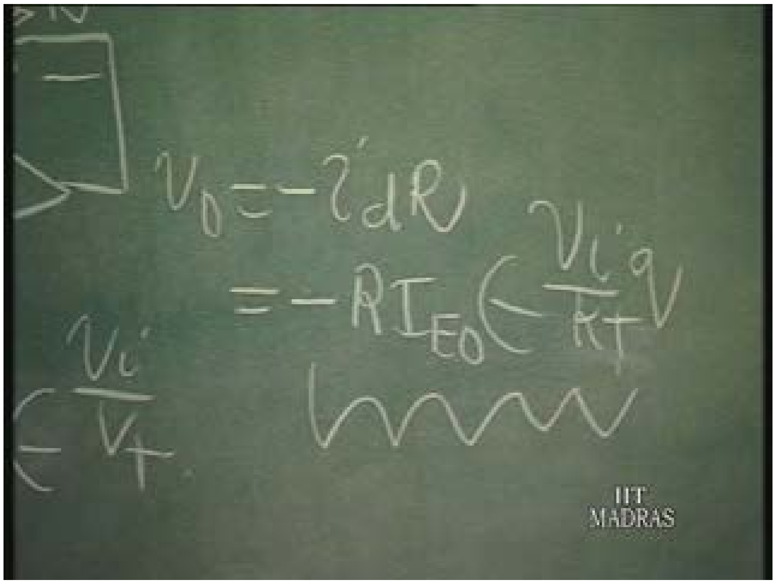

So, how to compensate for that? It is very simple. If I now introduce an attenuator here and make it Alpha and design that attenuator network to compensate for K T over q, that will take care of the temperature variation of this.

So, it is necessary that I put an Alpha network for this particular thing. That is, you put an attenuator here and I e naught has to be compensated for in a similar fashion by developing a voltage and then subtracting that voltage. Instead of just carrying out this voltage here to this point, we have to now put a voltage which is not only this but also of the forward voltage of another diode, which is having through it a constant current injected, just as we did in the earlier case. So, this is what has to be done.

This can be done in the following fashion. This circuit shows how the voltage here is arranged in such a manner that it is going to now compensate for the I e naught variation. Let us see how it is done.

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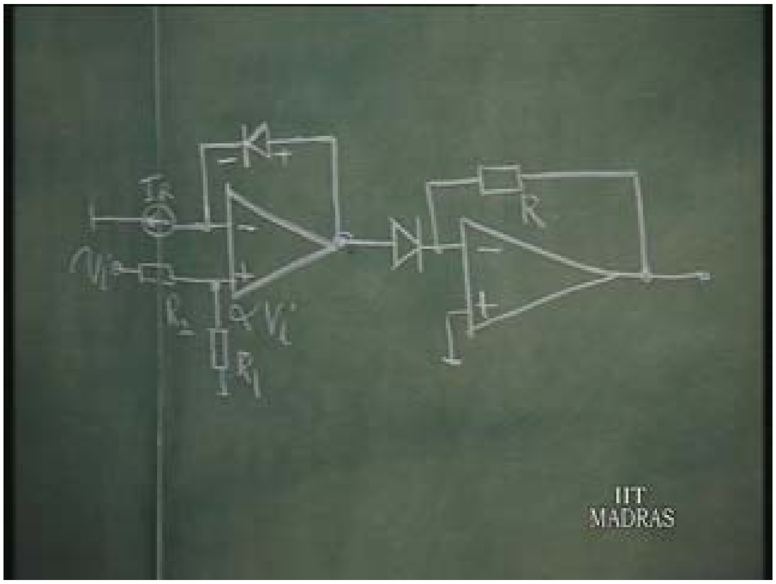

This is the antilog amplifier. So normally, if this is V i and this output would have been I E naught exponent V i by V d into...V i by V T into R, with a negative sign. So, it would have been... So, we will call this V i prime now. So, this is output V naught here; it is nothing but minus I E naught R exponent V i prime by V T. This the antilog portion. This I E naught, we want to remove and replace it with a constant, let us say, I R. So, this has to be replaced by I R. So, how do we replace this? Obviously now that to replace it by I R, I have to multiply it by I R into, let us say, this factor should be coming with I...in fact, I R by I E naught into I E naught.

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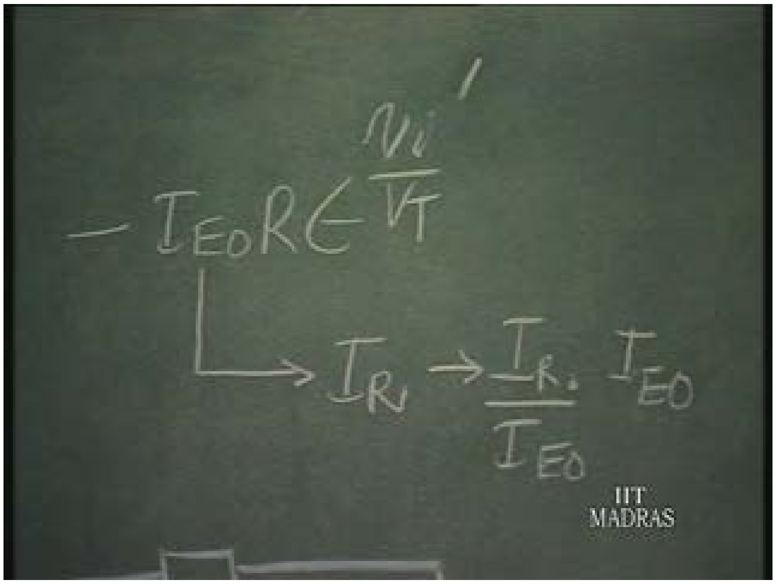

I R, if it is to be replaced with, I had to multiply it by I R by I E naught into I E naught. So, I had to extract a factor like I R into I E naught from something else because I E naught is to be replaced by I R. So, how do I get I R by I E naught? That is possible if I have a factor like this coming from the exponent log I R by I E, because exponent of log of I R by I E naught is I R by I E naught itself.

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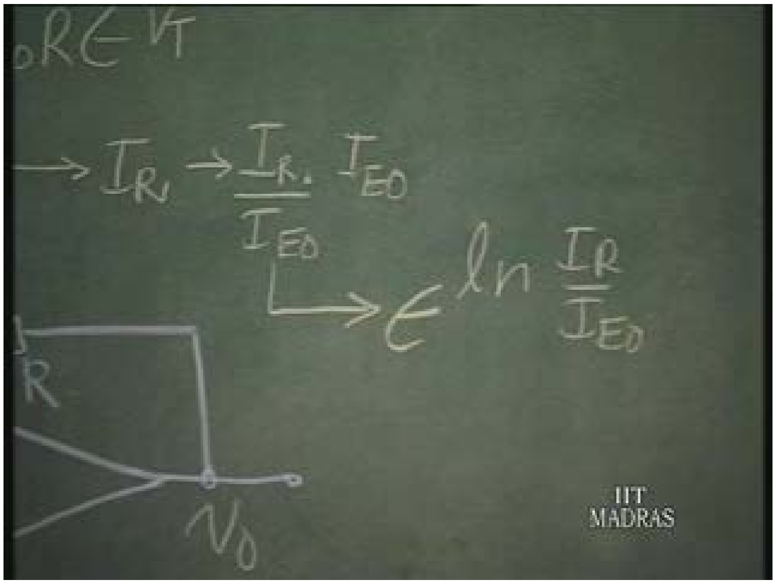

So, this factor can be obtained. That means, this into I E naught if you get, this is what it is going to be. It will be I R by I E naught into I E naught which will be actually giving I R. Now this thing can be done by multiplying by V T and dividing by V T here. Actually, V T log I R by I E naught is the voltage dropped across a diode which is biased by a current, constant current of I R. That means if I bias a diode with a constant current of I R, this voltage can be doubled which will give me a factor I R by I R. That means, actually speaking, if I want now this to be simply coming as V i, I have to have this V i plus this voltage coming at the input of this V i prime.

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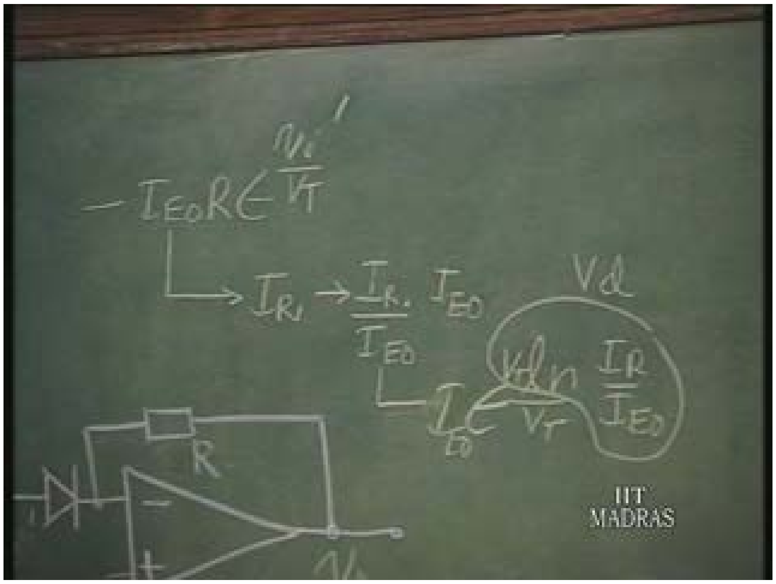

So, if it is normal, V i plus this voltage corresponding to this V diode, then we know that this factor is going to be exponent V i by V T into exponent V d by V T; and V d is V t log I R by I E naught and that V T, V T, gets cancelled. And therefore we have to have the voltage, this here, as V T log...I R...

So, this V T cancels with this V T and this factor I R by I naught here comes and this whole thing will be I R into R exponent V i by V T. So, that is what we are doing here. V i prime should be equal to...this is V i prime, should be V i plus the voltage across a diode whose current is I R; and this arrangement gives you that.

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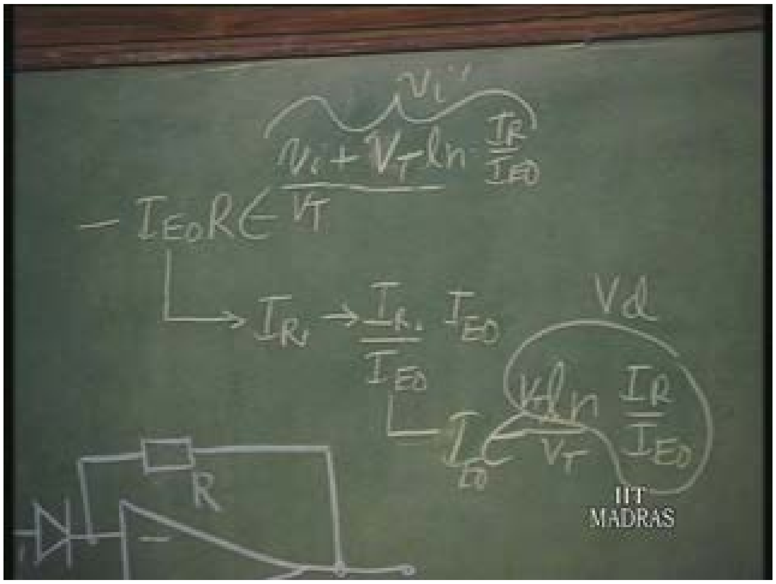

V i is applied here and the attenuator is put. So, Alpha is really R 1 by R 1 plus R 2. That is the voltage that is generated here, Alpha V i. If there is a feedback, this voltage has to be same as this voltage.

So, this becomes Alpha V i; and now, I have a current here I R flowing through this diode; flows through this diode, I R. So, this is I R. That means, the voltage here V diode is going to be V T log I R by I E naught. Therefore, this voltage, V i prime is going to be Alpha V i plus V diode. So, this is going to be Alpha V i plus V diode.

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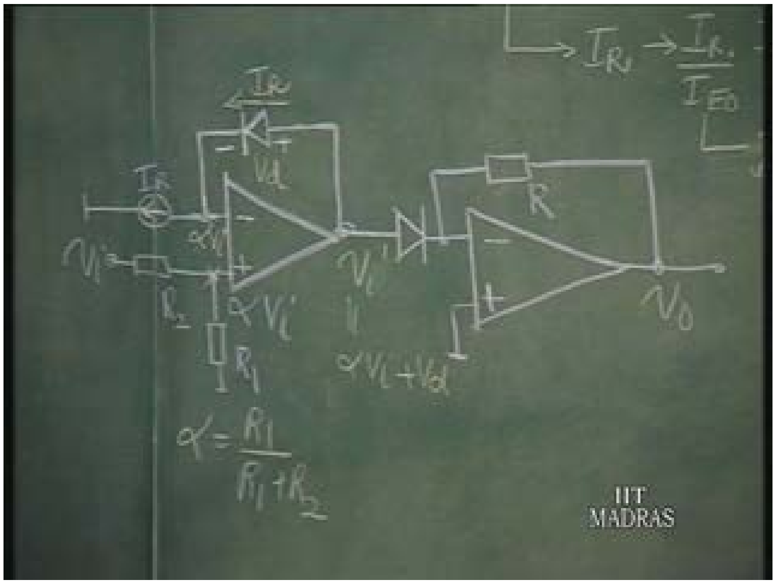

So, we have here an Alpha also coming into picture. That is to take care of V T variation with respect to temperature. So, V T by Alpha becomes independent of temperature over the range you desire.

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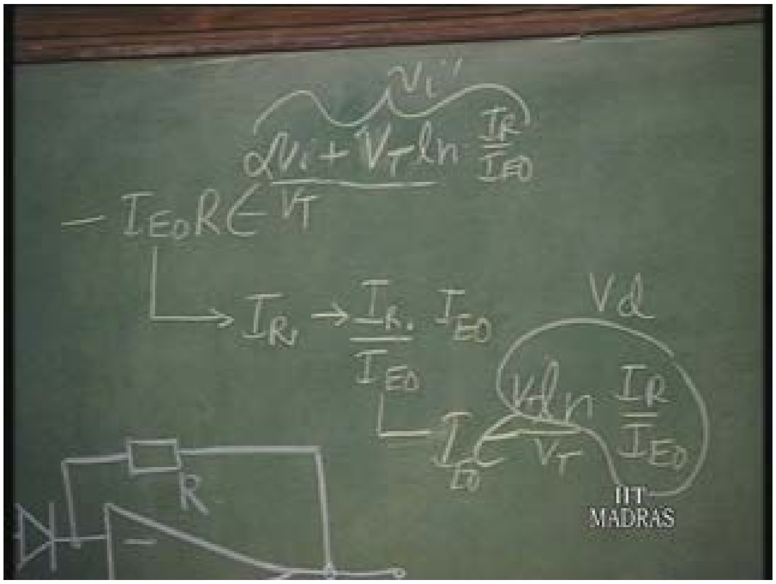

Just as in the other case, we can have V T by Alpha becoming independent of temperature by selecting a thermistor resistance here in the R 1 R 2 network so that over the range of temperature desire, the thermistor in combination with V T will give zero variation in temperature. That is an approximation only. So, that kind of arrangement gives you an expandor, data expandor which is temperature compensative.

So, let us now again find out what V naught is. V naught is going to be I E naught exponent...of this voltage, Alpha V i plus V T log I R by I E naught by V T. So, this is I E naught exponent Alpha V i by V T plus...into exponent. V T by V T gets cancelled; log I R by I E naught which is equal to I R by I E naught into I E naught exponent Alpha V i by V T, which is equal to I R exponent Alpha V i. So, this is a data expandor with temperature compensation; and this is what should be used as a what? – decoder, ultimately.

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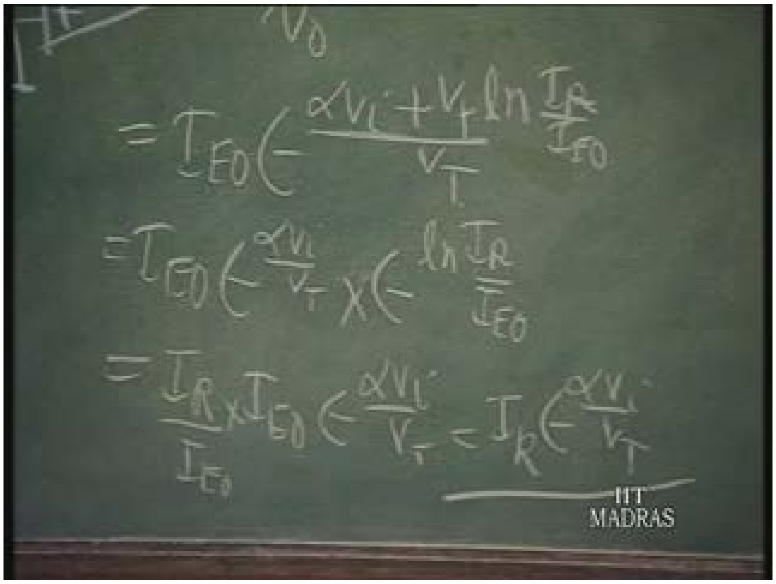

Once you code it in log form and then do the processing, and then you can do the decoding; so that whatever is occurring in the log form comes out of log form, gets expanded and comes in the normal form. So, this is what is normally done in the so-called antilog amplifier.

Now, this is not necessary when we want to adopt both log and antilog together to form what is called a multiplier. You will see this automatically, because...

Let us take log of V i. Obviously because of current dependence, it will be V T log I E naught by some R; let us say, V x by R x. This is the normal log amplifier without any compensation. To this, we add V T log V y by I E naught by R y. Then from this, we will subtract V T log V R divided I E naught R R.

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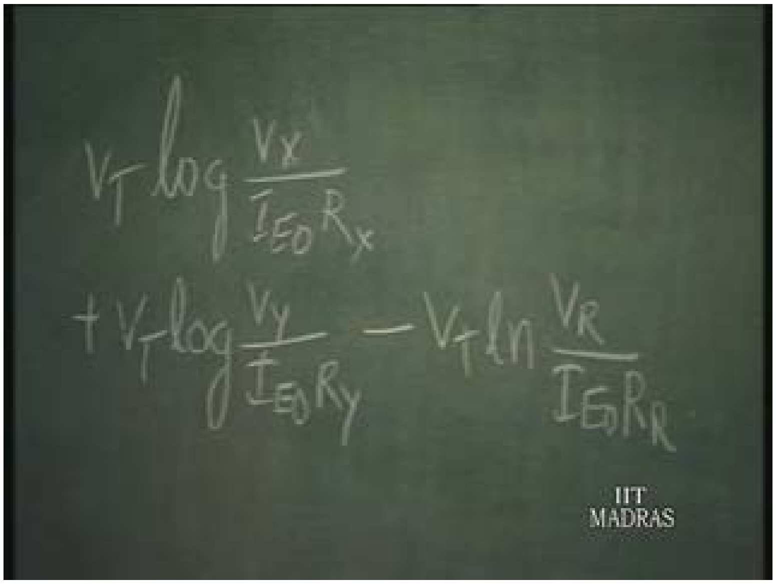

$$V_T \log \frac{V_x}{I_{E0} R_x} + V_T \log \frac{V_y}{I_{E0} R_y} - V_T \ln \frac{V_R}{I_{E0} R_R}$$

So now, you will see what happens. This whole expression is a log conversion where V T log...actually speaking, it is log, natural log. So, we have been maintaining it as log or l n.

So, we will put it as l n everywhere. So, V T log V x V y divided by I E naught squared R x R y; this is multiplied and this is divided. So, V R - you can see that the cancellation of one I E naught taking place automatically. So then, other I E naught is essential because when we take the antilog...let us take the antilog now.

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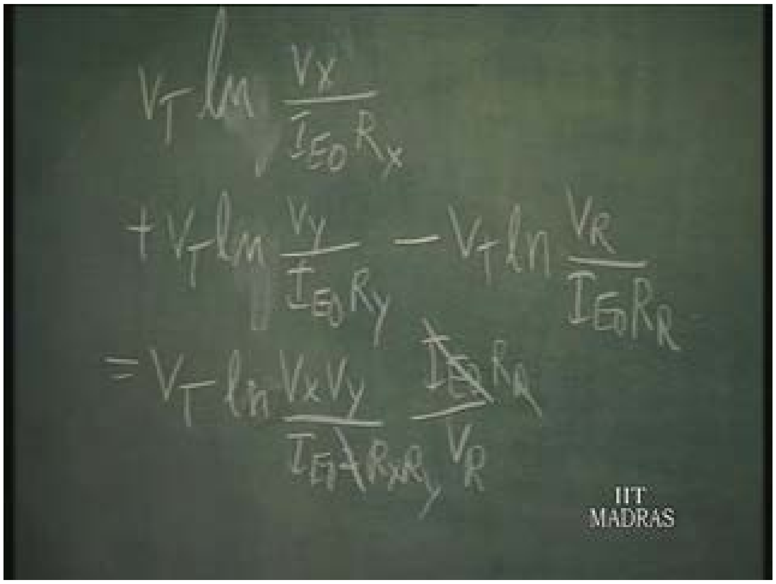

Antilog will give you I E naught, if this becomes the forward voltage; exponent of this voltage, which is V T log V x V y by I E naught, R x R y into V R divided by...nothing.

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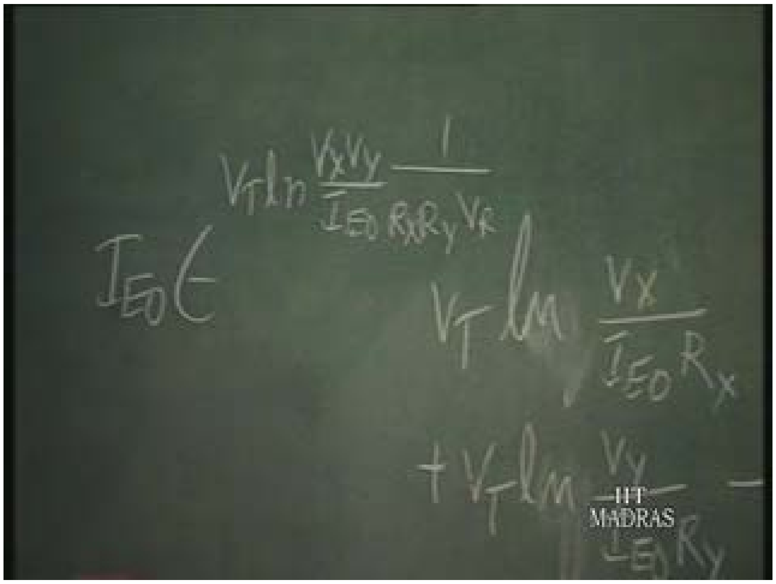

So this, if it is re-written now, this divided by V T...this gets cancelled; exponent log. Again, this is nothing but I E naught, V x V y divided by I E naught R x R y into V R. So again, I E naught, I E naught, gets cancelled. So, you will see that the...this is the current I. So, this current I into R is the voltage output and therefore that into R...Yes.

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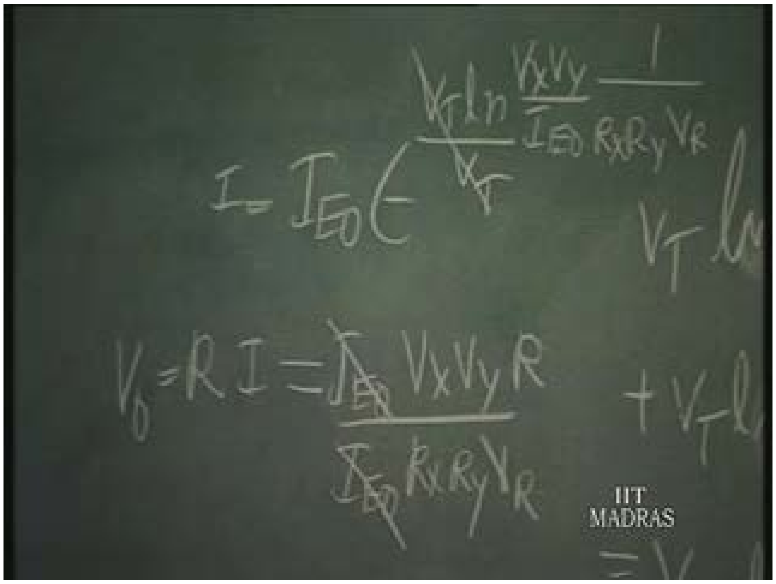

I think, in this whole expression, we have to have R R. Thank you. R R. So, this will be R into R R.

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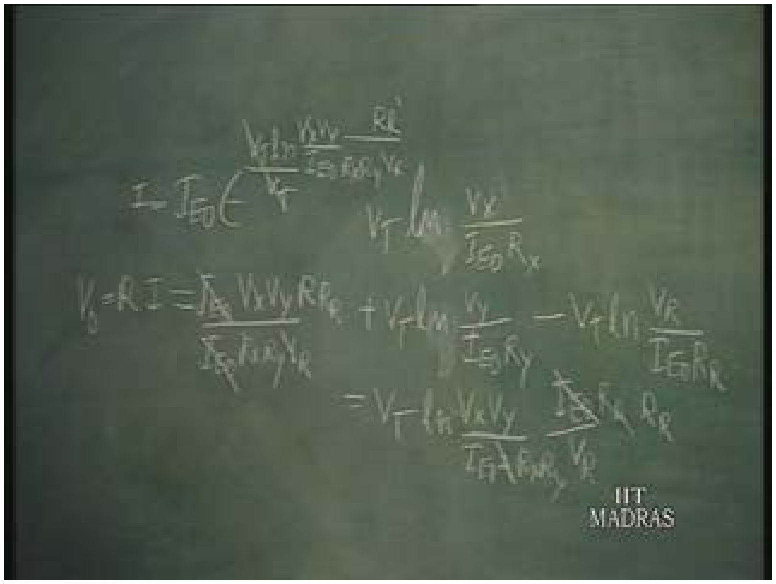

So, you get therefore an output voltage which is independent of effect of I E naught as well as V T.

So, when we design a multiplier we can simply take log amplifiers, add the voltages, diode voltages and subtract this reference log and then take the antilog of this effective diode voltage. That becomes effective diode voltage; and then it is to be multiplied by R, if we take the antilog; and output voltage will be totally independent of the effect of V T and I E naught.

So, when we design a multiplier, we do not have to do any compensation. It is automatically getting compensated because you are taking log and taking antilog.