Electronics for Analog Signal Processing - II
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Lecture - 20
ICs for Video & Tuned Amplifier Applications

Let us now come to specific integrated circuit chip, the configuration of which is given here. The exact values are not very important, which is usable for video or wide band application as well as tuned amplifier applications. We have already discussed that for a wide band configuration, we would like to have a pair which is common emitter connected to common base. This...any differential amplifier configuration of this type can be used for such cascode connection.

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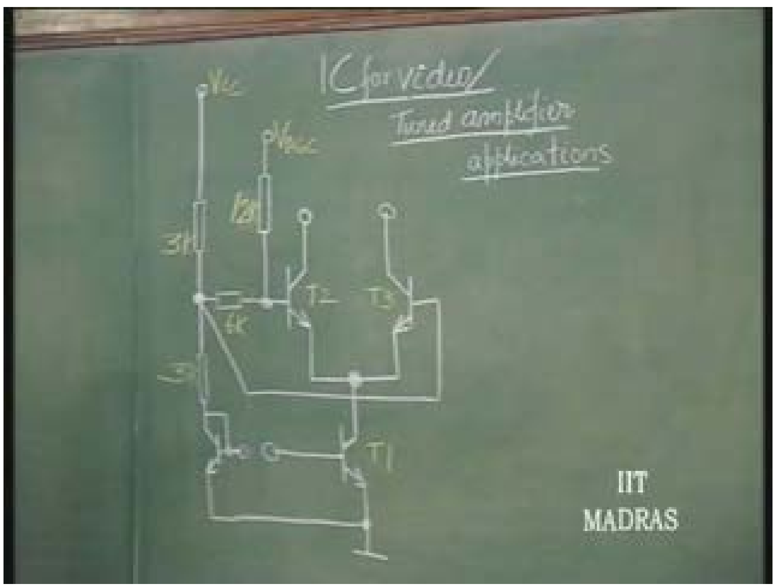

So, how do we get a cascode connection in this is what we are going to discuss. So, T 1 is actually the amplifier which is connected as common emitter here; and we will make this T 2 so that this is the common base amplifier. So, this combination - T 1 and T 2 can be used as a cascode. If, for example, I connect externally externally I connect V C C C to this so that this transistor may not come into picture in the actual structure and here I connect the load. So, let us see. I connect here the load, external load. In the case of a wide band amplifier, it is resistive; in the case of a tuned amplifier, it will be a tuned circuit.

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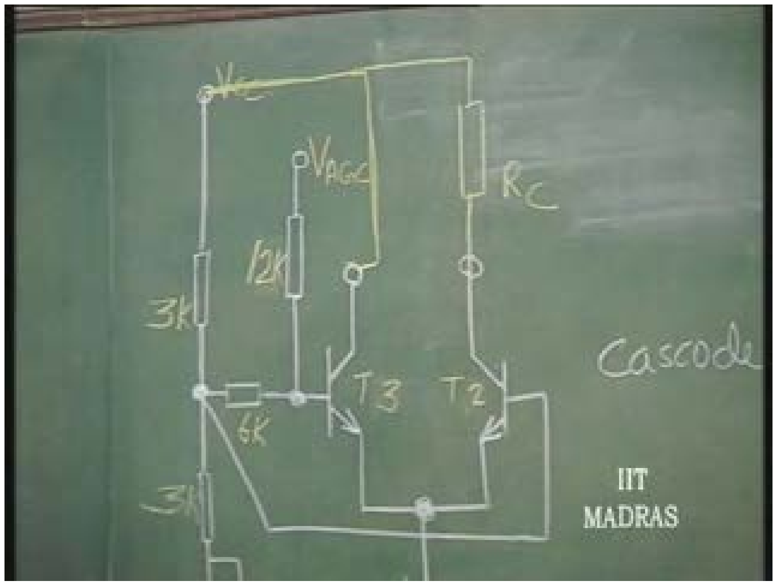

So this, we will come to at a later date. V A G C and... I am going to short circuit this so that this is the external connection; and let us say, if I connect like this, then I can feed the input to the base of this. This is the common emitter transistor and this is the common base, if I externally ground this by means of a capacitor.

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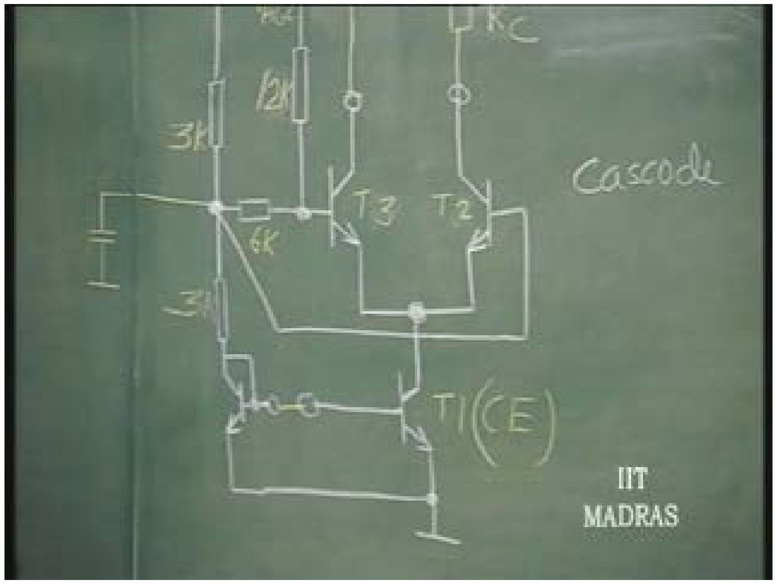

So, this is signal wise grounded by means of a capacitor. This is connected to V C C and we see that if A G C terminal is left free, there is almost no current through c k...6 k and the base of this T 2 is at the same potential as the base of T 3; and therefore, these two currents will be very nearly one and the same.

So, the current in this is going to be halved if V A G C is zero. Current is going to be halved. That means the gain is halved. Without this transistor, the gain would have been g m into R c. So, minus g m into R c is the gain without the transistor. With V A G C is equal to zero, the gain is going to be halved.

If now I apply a positive voltage here so that the entire current is diverted to T 3 and nothing is left for T 2, then the gain is going to be zero. If V A G C with a certain positive value, I can make the gain go to zero. So, the gain varies from zero to minus g m R c by 2 to g m R c.

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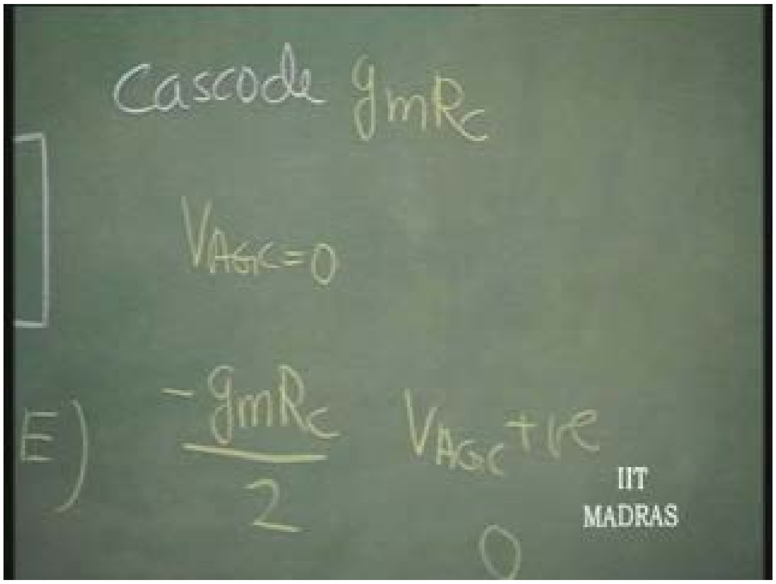

So this V A G C therefore can be used to change the gain of the cascode structure. We had earlier learned about the differential amplifier and we have seen that as we apply a positive voltage here, the current gets shifted to this. As we apply a negative voltage, the current gets shifted to this. So, by applying suitable voltage which we are calling as V A G C, we will understand why this is called A G C later. By varying this V A G C voltage applied at this point, we can therefore control the gain. So, that is why it is called V A G C, gain control. g c - gain means automatic.

If this is permitted to be done automatically, we will see why such a thing is needed later; then it is called V A G C. But by applying an independent D C, we can see whether the gain is varied from zero to g m into R c, minus g m into R c.

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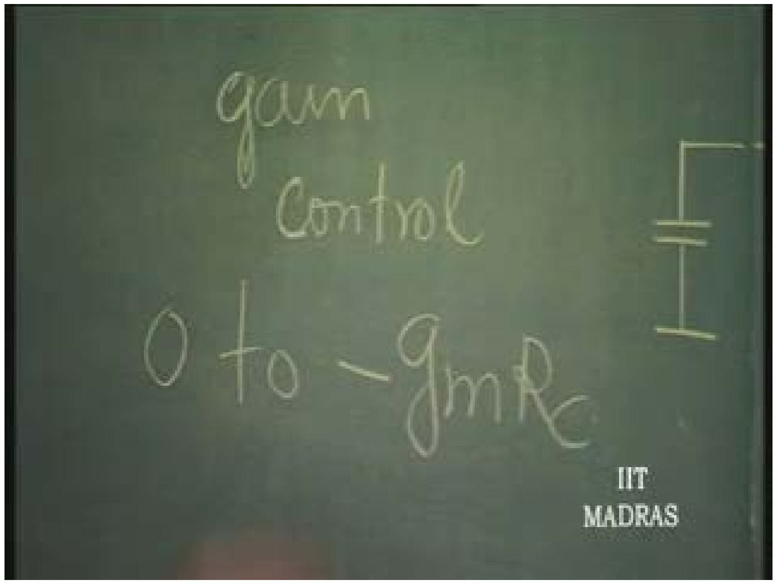

So, you can therefore see that there is an advantage in this structure. That it can be used as a cascode with this conventional current source for the differential amplifier being used as a common emitter amplifier; and one of the two transistors of the differential amplifier being used as the output stage, the other transistor being used only for controlling the gain.

So, this configuration is a very useful configuration because in a straight forward cascode structure, if you want to vary the gain, you have to vary the emitter current. If you vary the emitter current, we have seen in the last class that y 1 1 and y 2 1 parameters also vary.

If y 1 1 and y 2 1 parameters vary, then when we are using it as a tuned amplifier, the Q, the bandwidth, all these things will vary; whereas this current remains constant; and it is in this division of currents that is changed so that the parameter y 1 1 and y 2 1 remain the same, when A G C takes place. That kind of advantage is offered only by this kind of structure.

So, this is very popular in all tuned amplifiers where it may be coupled by means of an I F transformer at the input and a tuned circuit may be put at the output which may be an I F transformer to the next stage.

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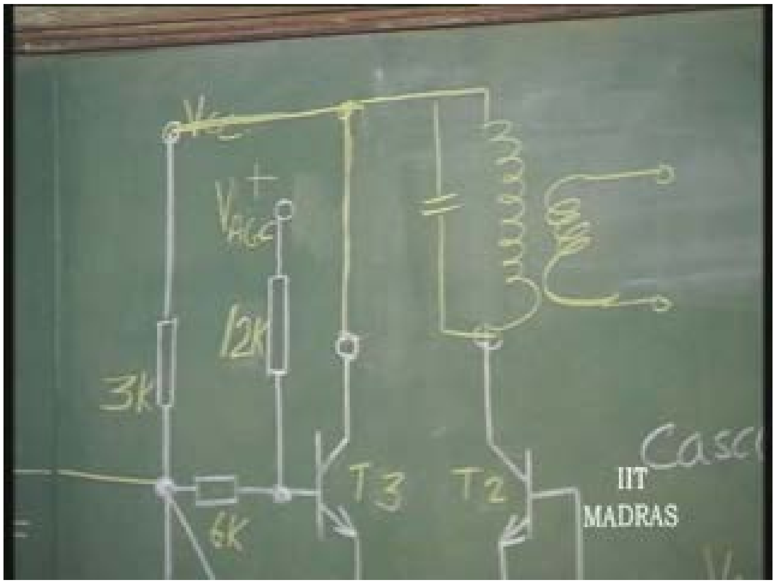

So, these are called tuned amplifiers; tuned at the input. What do you mean by tuned? That means resonant at a certain frequency called I F or R F; whatever be the frequency at which you want to design the amplifier. That is called tuning; tuned at the input and tuned at the output.

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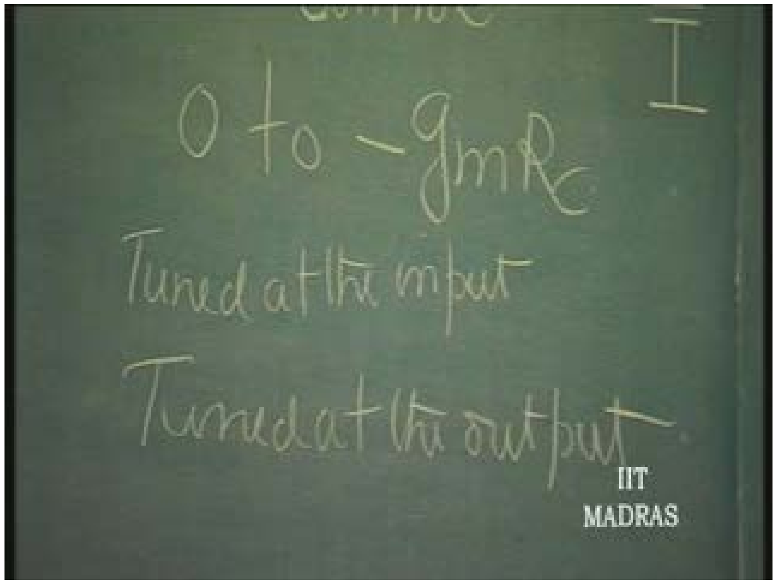

Now, let us understand what is meant by tuning. Let us say, the input impedance of cascode structure Y i is equal to Y 1 1 because Y 1 2 is zero; because Y 1 2 is zero. Because Y 1 2 is zero, there is no interaction between output tuned circuit and input tuned circuit. Otherwise, it will be very difficult for us to tune the input, independent of the output. Output and input will start interacting with one other, one another because Y 1 2 is zero.

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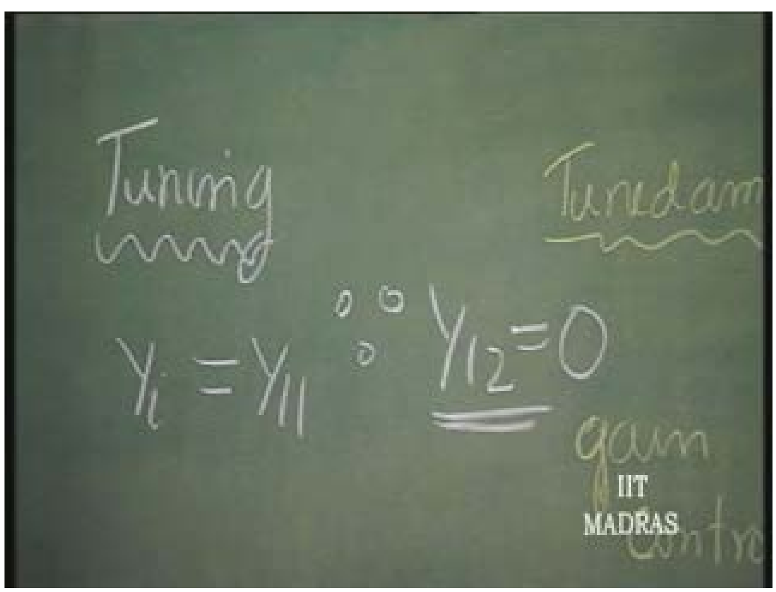

That means the circuit is really unilateral. This we had discussed earlier in the beginning of the course, first part. So, in any tuned amplifier, it is necessary for us to have Y 1 2 equal to zero, so we can do independent tuning of the input as well as the output. What is tuning the input? Y i is equal to Y 1 1 but Y i total at the input is nothing but Y 1 1 plus Y s, because this is the signal source.

Tuning means making the real part of... that is, making the imaginary part of Y 1 1 plus Y s go to zero. This is what is called tuning; making the imaginary part of Y 1 1 plus Y s go to zero.

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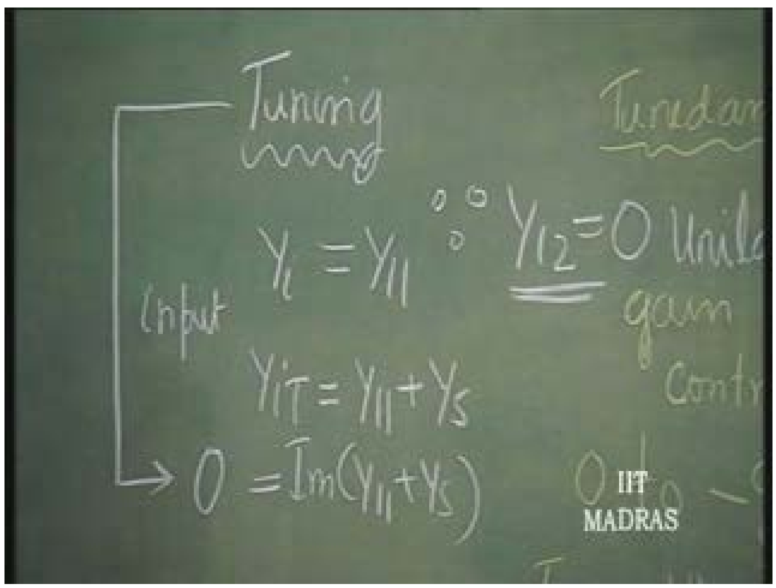

This can be represented as... Y 1 1 can be represented as g 1 1 plus j b 1 1 and Y s can be represented as g s plus j b s. Then, what is tuning? b 1 1 plus b s is equal to zero. This is the mathematical part of tuning.

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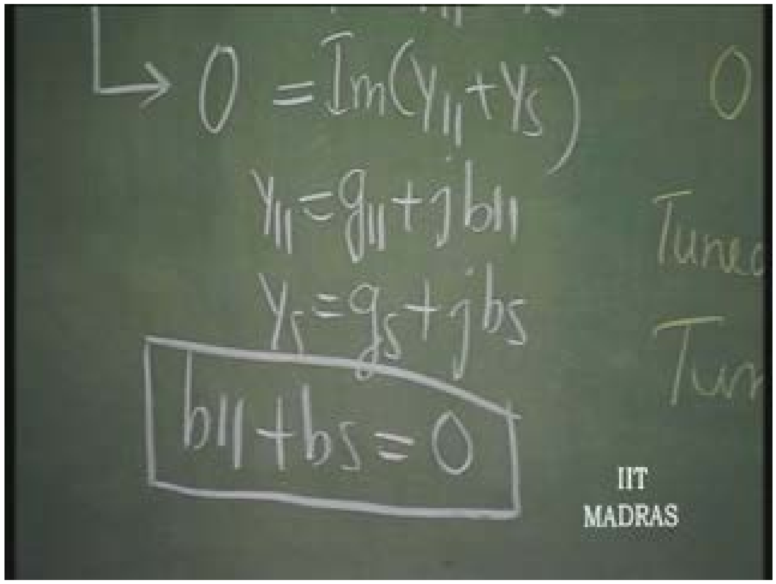

The susceptance of the input device plus the susceptance of the source is made equal to zero. If this is capacitive, then obviously this has to be inductive in order to make this equal to zero. So, this is what is meant by tuning. In such a situation, the entire Y i total is going to be twice g 1 1 because g s is made equal to g 1 1. This is called matching.

This kind of structure with matching at the input is done in order to transfer maximum power from the source to the input. So, maximum power transfer occurs due to matching, when g s is made equal to g 1 1. Then, Y i total is equal to g 1 1 plus g s which is twice g 1 1. So, Y i total at the input is twice g 1 1.

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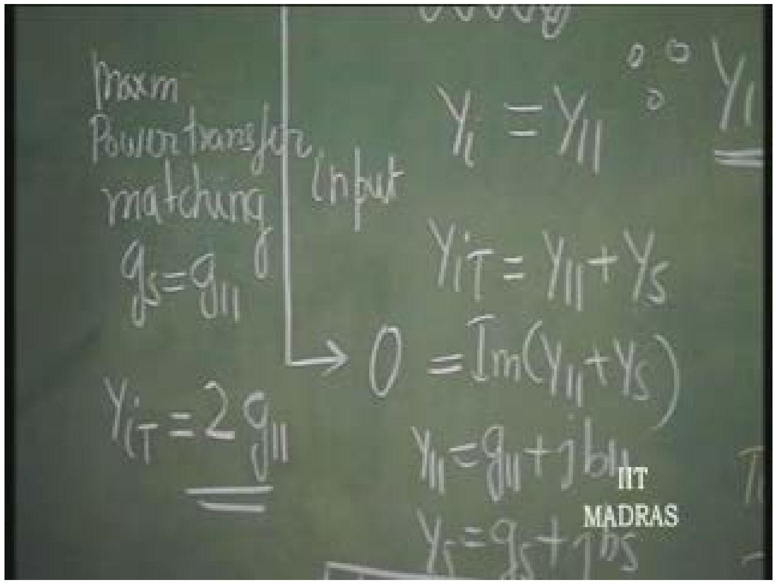

Similarly, tuning at the output is to make b 2 2 plus, let us call this, b L, load; because Y naught total is Y 2 2 plus Y L, total admittance at the load end, because again Y 1 2 is zero. Otherwise, it would have been got affected by the input admittances. So, Y naught total is equal to Y 2 2 plus Y L. b 2 2 plus b L is made equal to zero. And matching occurs when g L is equal to g 2 2 and Y naught total at that point is equal to g 2 2 plus g L, which is twice g 2 2. So, this is tuning at the output.

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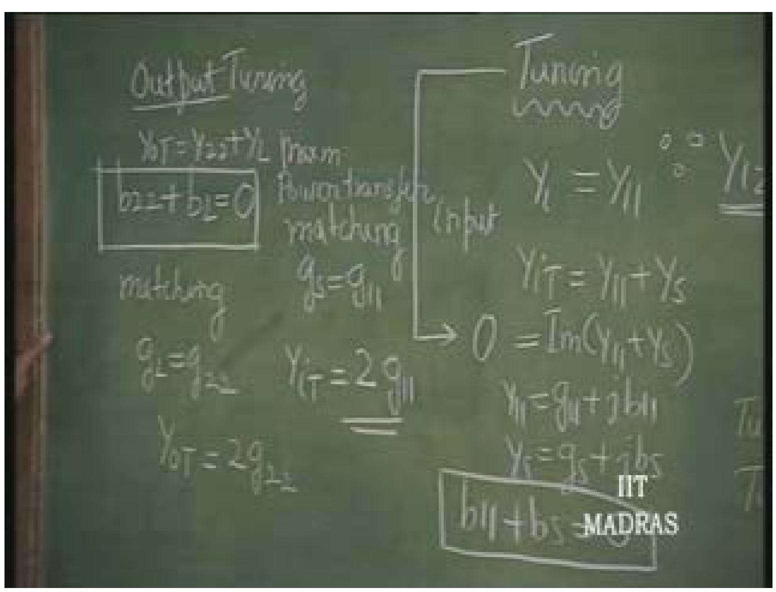

This kind of design is called conjugate matching. That is, total susceptance at the input is made equal to zero; total susceptance at the output is made equal to zero, by selecting the load admittance as conjugate of output admittance and source admittance as conjugate of input admittance. That is why it is called conjugate matching for maximum power transfer. Conjugate matching is done for maximum power transfer.

So, given the parameters like this, Y 2 1, then Y 1 1 and Y 2 2, we can find out what is called as maximum available gain; maximum available gain – M A G. This is one of the important parameters of tuned amplifiers, power amplifiers – maximum available gain. Particularly, if you are designing such R f power amplifiers as transmitting stage, etcetera, you would like to use a device with a certain power gain called power, maximum available gain. What is maximum available gain? Let us understand.

The input is conjugate match so that the input source can deliver its maximum power to the input of the amplifier. Then amplifier amplifies with a certain power gain and output load, it is delivered by the amplifier, when it is matched at the output also, conjugate matching. Then, whatever gain we get is characteristic of the amplifier that you are using because you have optimized things at the input as well as the output; and that is called maximum available gain. Now, that is a power gain.

Power gain, by definition, is nothing but voltage gain into current gain, conjugate. So, if I have voltage gain expressed in terms of Y parameters which you can look back, voltage gain is Y 2 1. Y 2 1 is same as g m at low frequencies into R c; g m into R c. Y 2 1 is replacing... in this case of Y parameters, the g m. R c is nothing but 1 over Y 2 2 plus Y L.

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And in our case, that is the voltage gain. In our case, Y 2 2 plus Y L is really equal to 2 g 2 2. This is the voltage gain; and current gain is nothing but Y 2 1 again, divided by Y 1 1 plus Y s. That is current gain. Y 2 1 is nothing but transconductance actually, which is nothing but input voltage output current divided by input voltage. And Y 1 1 plus Y s is nothing but input voltage by output...input current divided input voltage.

So, if you take the ratio of this, it is Y 2 1 divided by Y 1 1 plus Y s; and conjugate of this, current gain into voltage gain conjugate, or voltage gain into current gain conjugate...

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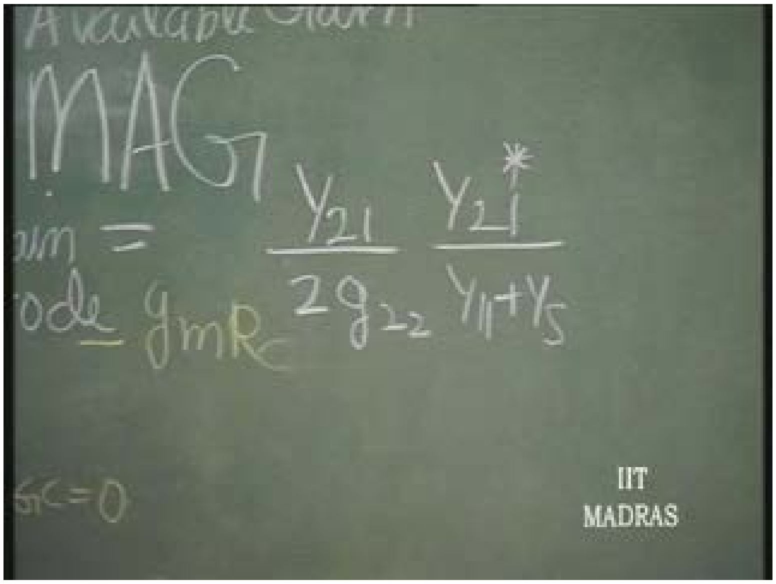

...and this part is 2 g 1 1 and Y 2 1 Y 2 1 conjugate is really speaking, defined as Y 2 1 magnitude square. This is what is called as M A G.

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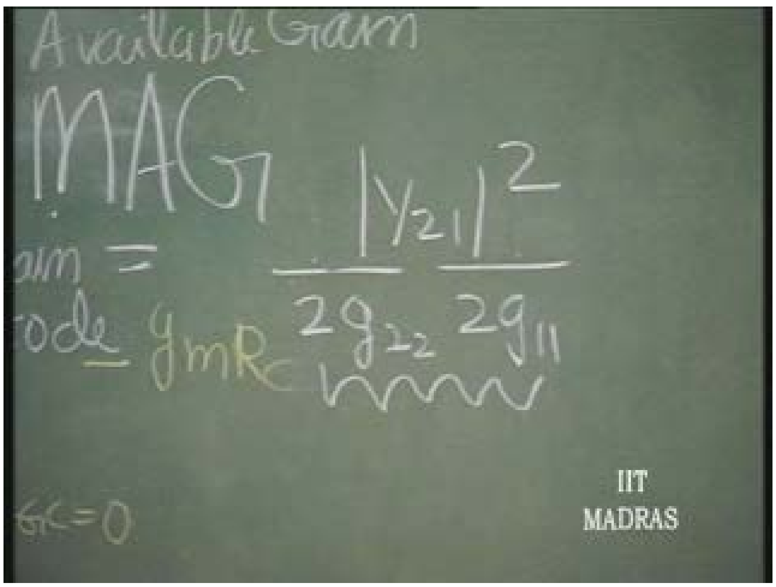

It is nothing but 4 g 1 1 g 2 2. Y 2 1 square, magnitude square, divided by 4 g 2 2 g 1 1 is what is defined as M A G. This is normally given by the manufacturer. If Y 2 1 is known, g 1 1 is known, g 2 2 is known, you can compute this and that is the maximum available gain. This is normally expressed as 10 log Y 2 1 square by 4 g 2 2 g 1 1, power gain being... Power gain, it is in terms of decibels. Power gain in terms of decibels.

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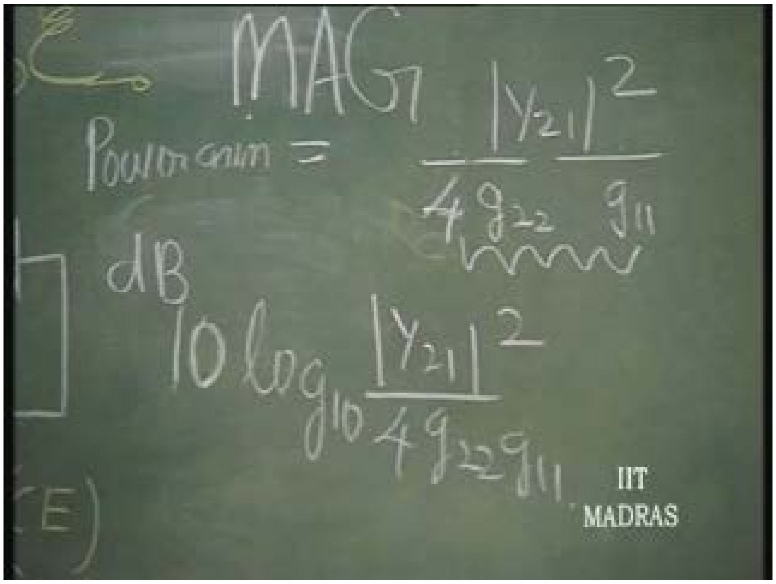

And suppose let us say, you are asked to design an I F strip whose gain is 30 decibels. And you know that you have a device whose M A G is 20 decibels; and you know that you have to use more than one stage. In order to get for this I F strip, a gain of 30 decibels, you have to use more than one stage because single stage trans active device which you are using, this cascode device, is giving you only 20 decibels.

So, this is very useful for deciding as to how many number of stages you must use in your system in order to obtain the desired sensitivity for the receiver, whether it is radio receiver or television receiver. And the sensitivity of the receiver is always determined primarily by the I F strip; how good your I F strip is.

So, this part of the design is going to involve only these things: tuning at the input, tuning at the output and evaluating the maximum available gain. And please note that in this arrangement, this current is going to be divided by V A G C. If V A G C is zero, it is divided equally; if V A G C is large positive, then most of the current goes here. Nothing goes here. And the gain is zero. If V A G C is negative, most of the current can be diverted to T 2 and therefore the gain is going to be the highest, as given by this. So, the gain can be controlled by V A G C.

Now, how the gain is controlled by V A G C is very simple. This potential, if this is let us say, V C C is 12 volts, this potential is going to be very nearly half because 3 K, 3 K, is put. Of course, it is going to be slightly different from half because of this point 6. So, it is around 6 volts; and therefore, you will see that for V A G C of about 6 volts value, the gain is going to be half the maximum. When V A G C is coming down to zero, most of the gain goes to this. This is zero. Therefore, this is at a positive potential and this is at a lower potential; and therefore all the current is diverted to this.

So, the gain is maximum when V A G C is zero; when V A G C is 6 volts, gain is half - g m r c by 2 or whatever it is; and then, when V A G C goes positive by some value, then, the gain can become very low. We can actually find out what is the variation in V A G C in order to create the required variation at this point from base to base; in order to divert the current from here to here. Now that part of it can be easily evaluated because we have seen earlier that if this is i E 1and if this i E 2 let us say, and this is i E 3 we will call it, this is i E 1.

i E 3 plus i E 1 is nothing but... i E 1...or, this is actually 2, we will put it. This is i E 1... equal to i E 1.

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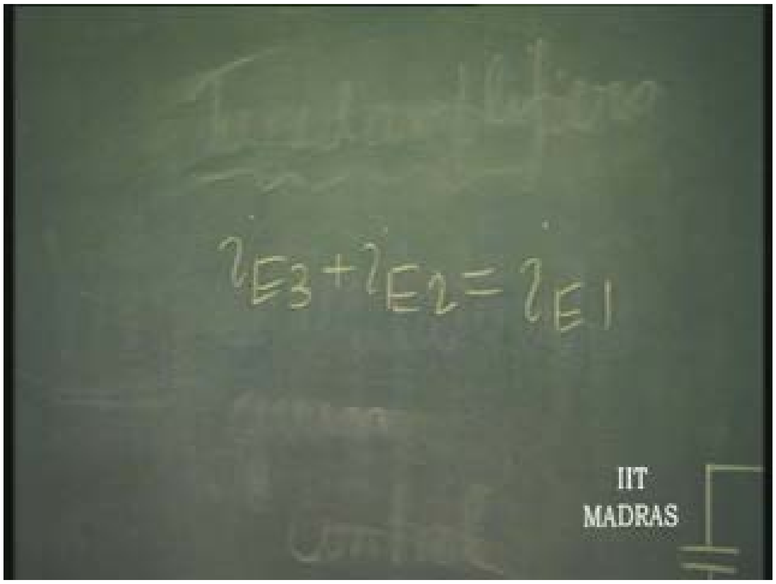

i E 3 plus i E 2 is always equal to i E 1; and i E 3 and i E 2, they are governed by... i E 3 is i E naught into exponent V B E 3 by V T. i E 2 on the other hand is i E naught exponent V B E 2 by V T. So, i E 3 by i E 2, the ratio of the two currents is governed by exponent V B E 3 minus V B E 2 by V T.

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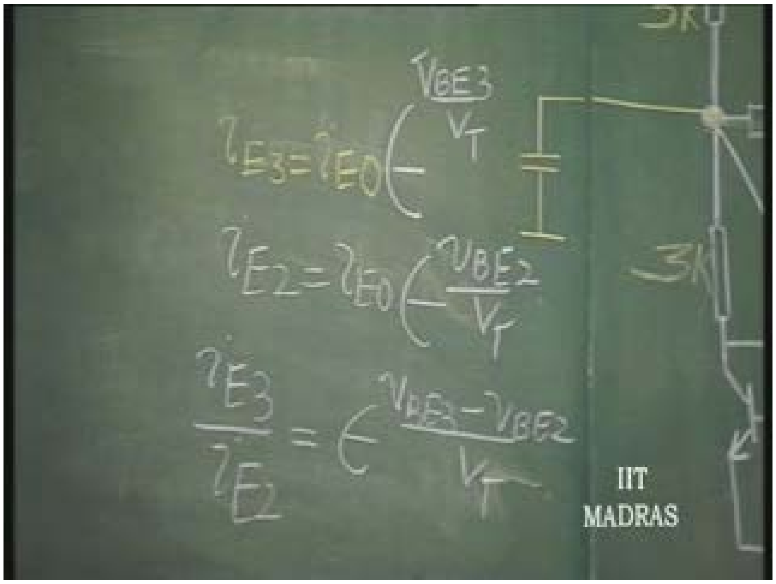

Now, what is V B E 3 minus V B E 2? This voltage minus this voltage, which is the voltage across 6 K.

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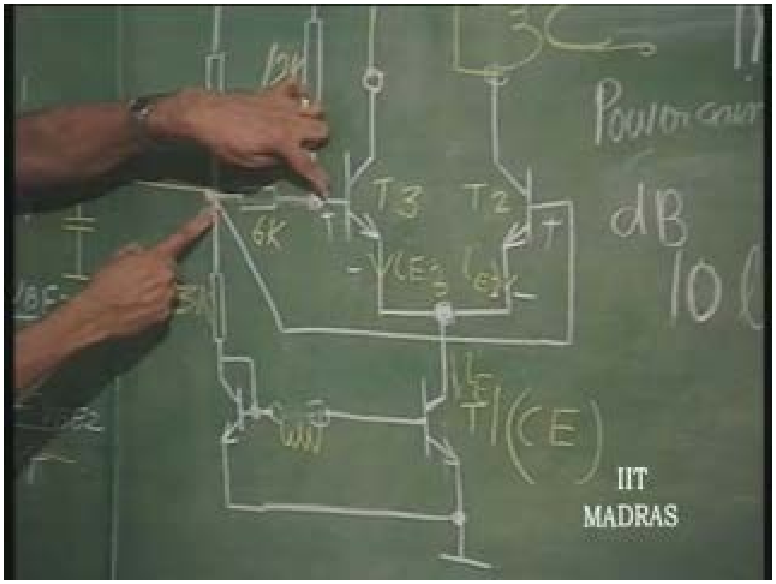

So, this can be written as V B E 3 minus V B E 2, the voltage across 6 K; and voltage across 6 K is governed by voltage V A G C with an attenuation factor. So, voltage across 6 K is governed by how V A G C is phased.

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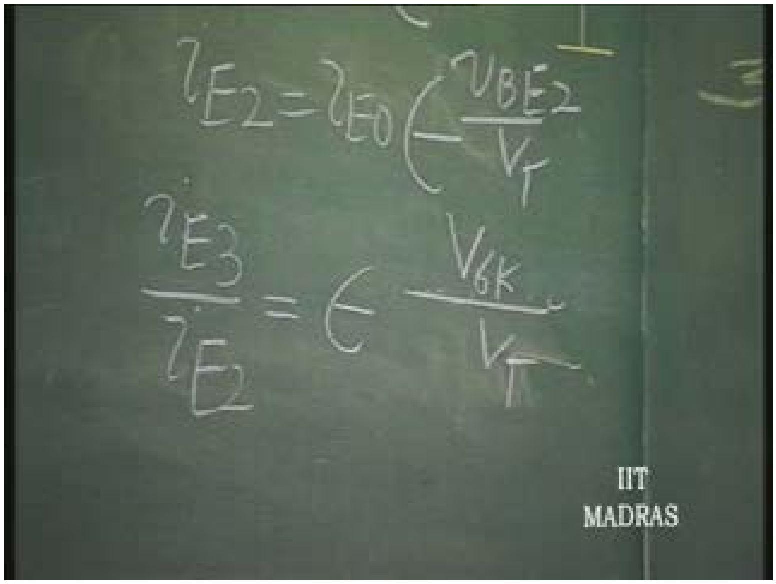

Now, i E 3 plus i E 2 is the total current of i E 1. Now out of this total current i E 1, let us say 10 percent is i E 2 and 90 percent is i E 1 or i E 3 and 90 percent is i E 2 or vice versa. This is 90 percent and that is 10 percent.

Why we take 10 and 90? Because, this is an exponential relationship and we cannot say 100 percent and zero percent. It occurs at infinite voltages. So, we consider when it is 10 percent here and 90 percent here, or 90 percent here and 10 percent here, as the voltage swings necessary here, in order to switch these transistors completely to off or on.

So, in this case then, the ratio with exponent V 6 K by V T equal to, let us say, 10 by 90, one case; exponent V 6 K prime by V T as 90 by 10, as the range of V 6 K variation which will cause the required change of gain from zero to 100 percent.

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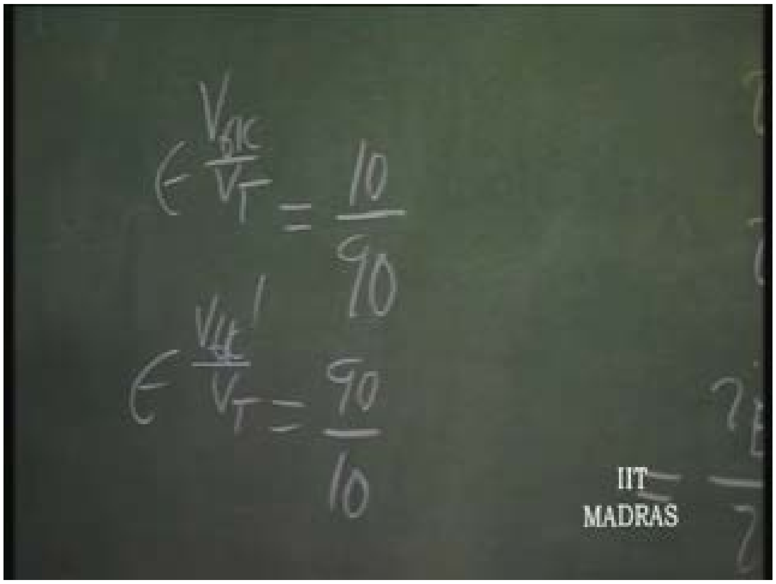

So, if this is divided by the... one is divided by the other, we get V 6 K minus V 6 K prime by V T as being equal to 81; or V 6 K minus V 6 K prime is equal to V T log 81, which is equal to...1 naught...109 point 86 millivolts. So, you can see that if I am to control the voltage here, the change in voltage necessary at the basis is about 110 millivolts; approximately equal to 110 millivolts. V 6 K prime minus V 6 K is equal to 110 millivolts. So, this is... this is the change that...

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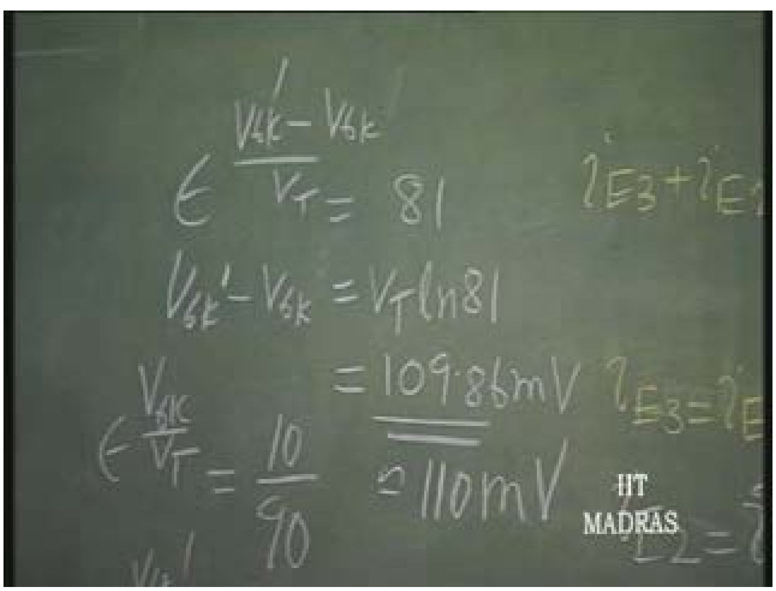

Since it is the change, it does not matter whether it is one voltage change or the other voltage change. So, this is the change in voltage across...We will call it as Delta V 6 K, needed. That is equal to 110 millivolts, for any such differential amplifier. This is very clear.

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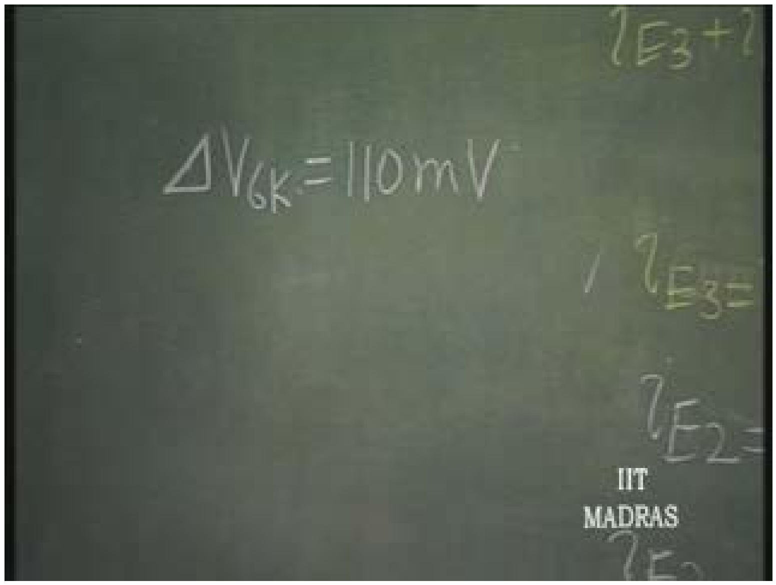

Then, what is the change in... What is Delta V A G C for this circuit? Let us work it out. If Delta V 6 K is 110 millivolts, what should be Delta V A G C?

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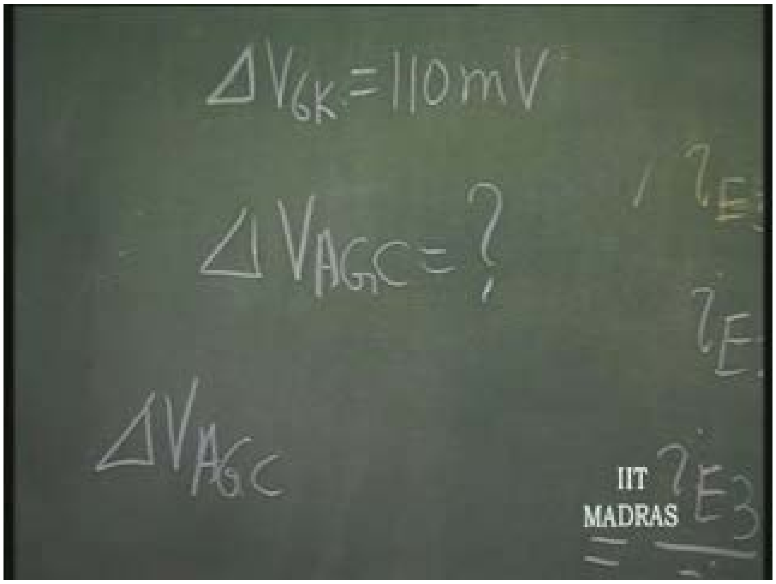

These two voltages - this is V Gamma and this is V C C. They are constant. Their contribution here is of no significance because that is a constant contribution. We want...when this is changed, what is the change in voltage? That means it is enough if we consider only Delta V A G C here. Delta V A G C is going to result in an attenuation. There is a 6 K, 12 K and a 6 K, and from here to ground we have 3 K parallel 3 K; that is 1 point 5 K.

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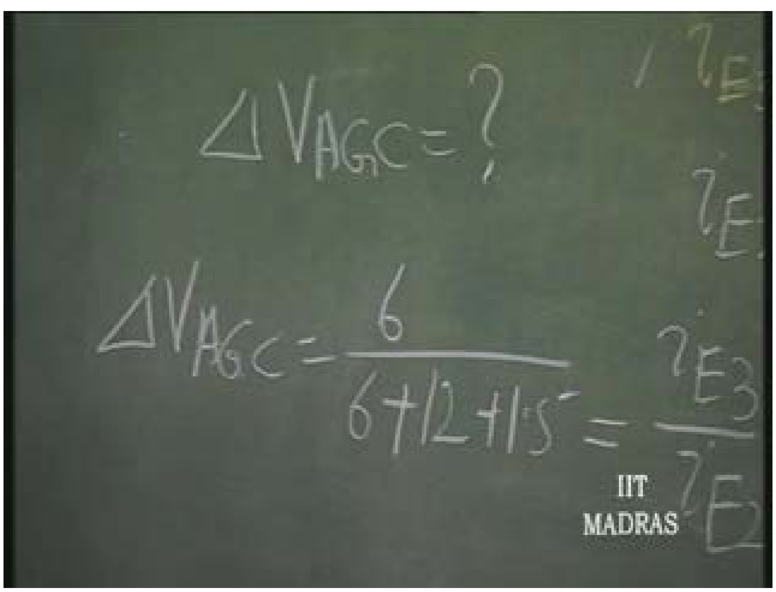

So, the change is across 6 K divided by 6 plus 12 plus 1 point 5. That is the attenuation factor; and Delta V A G C is going to be attenuated by this extent and that is Delta V 6 K. Delta V A G C into this factor.

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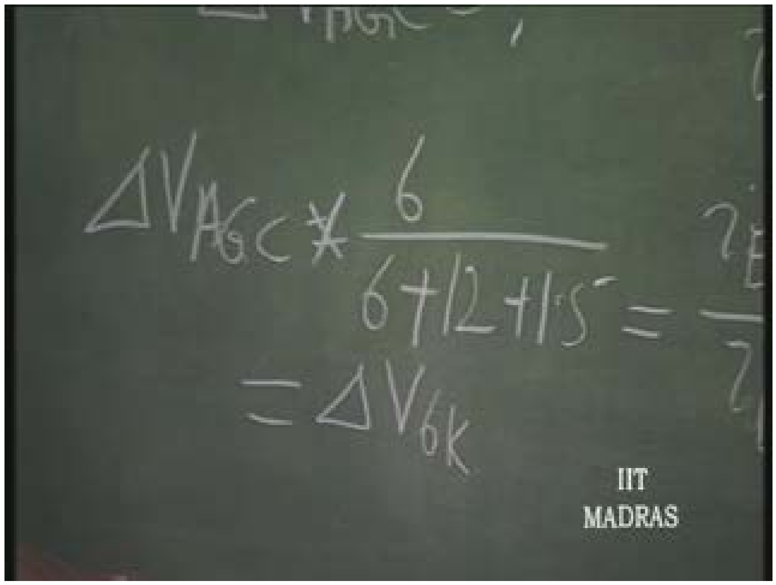

This is 6 divided by 19 point 5. So, if Delta V 6 K is 110 millivolts, then Delta V A G C is 110 into 19 point 5 by 6. How much is this millivolts? About 300 and odd. 357 point 5 millivolts.

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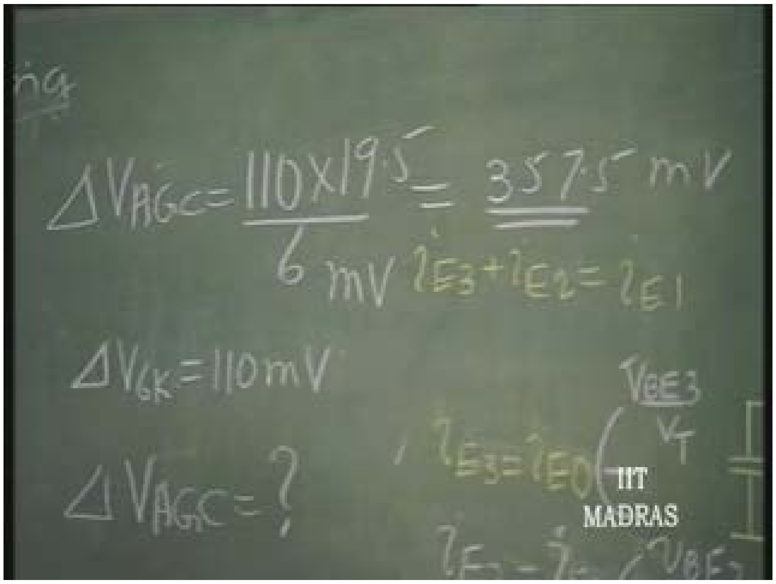

So, that is the change that is required at... in order to change the gain from 10 percent to 90 percent. That is the change that is required. That will be useful for our design.

Now, where ever this V A G C is used... you know, in all your receivers, because of the weather conditions and all that, because the transmission takes place through ionosphere, there are what are called e layer, f layer, etcetera, because of some reflections there, these short wave transmission takes place; and suppose there is a receiver that receives signal. The signal level at the receiver keeps on changing, fading; sometimes it is very strong, sometimes it is very weak. If such a thing is amplified by an amplifier, sometimes the amplifier signal is too strong for the power amplifier. So, the power amplifier may get distorted and sometimes it is too weak that you cannot hear anything. So, this effect is seen as fading.

So the output, you will hear very clearly. Then at next moment, you may not hear. This has to be prevented. How to prevent this? That when the signal level is low, you want the I F gain to be high. When the signal level is high, you want to purposely reduce the I F gain so that the output to the power amplifier remains constant drive so that distortion is not there. This is what is called automatic gain control. This should be done by finding out what the I F gain should be. So, that can be found out from measuring the I F amplitude itself.

So, in the detector, you can actually get a D C, proportional to the I F amplitude, and that D C is made to control this current division here. That is this V A G C. That D C that you obtain at the detector is the V A G C which will control all the gains of the I F stages as well as R F stage. If there is a communication receiver it is fed to the RF stage also, and also to the mixer. So, all these gains are controlled by the D C that is obtained at the detector.

So, that is why it is called automatic gain control. So, your circuit functions very satisfactorily without this irritation about fading, only when your A G C is functioning satisfactorily. This is also called automatic volume control A V C or A G C, automatic volume control or gain control.

So, you will see that this is a must in all receivers. And that is very conveniently applied here so that your parameter Y 1 1 and Y 2 1 do not vary because this current remains constant. In a regular cascode structure, without this arrangement, these parameters vary and this gain also varies because A G C is necessary. This current varies in order to vary the gain. Then automatically, the parameter varies; the tuning also gets disturbed; whereas in this, this current remains constant as A G C voltage changes and therefore the parameter Y 1 1 and Y 2 1 never change and Y 2 2 also does not change here because this reverse bias voltage does not change because of the coil here.

So, this is a very nice structure for a mixer stage or an R F stage or an I F stage, depending upon the frequency of interest to you. So correspondingly, a tuned circuit at the input and a tuned circuit at the output can be put. If it is an IF stage, this is I F and that is I F. If it is a mixer stage, this is I F. But, this is a mixture of local oscillator frequency as well as the incoming frequency. The incoming frequency can be given here and the local oscillator frequency can be given here because this acts as a multiplier or a modulator; and therefore, it is also used for a mixer. It can be also used for amplitude modulation. It can be also used for balance demodulation. So, this is a very versatile circuit. It is only dependent upon what kind of load and inputs you use. The function is a gain control.

Now that we have seen clearly how a wideband stage can be used for tuned amplifier, tuned R F amplifier or tuned I F amplifier, depending upon the center frequency, you call it R F or I F. Now, I F is a fixed frequency amplifier; R F is a variable tuned amplifier. So, it is difficult to design R F stages compared to I F stages and that is why most of the gain of a communication receiver is packed in I F rather than in the R F stage. R F stage has to work satisfactorily over a wide range with narrow band and it is fairly difficult design.

Now, these wide band pairs let us discuss. One was already cascode - common emitter with common base. Again, if you use common collector which is by itself a wideband structure, common collector feedback structure, with... common collector with common base, which is also a wide band structure. This is a feedback structure, we have understood; complete voltage feedback. This is complete current feedback; both of which are wide band structures by themselves compared to common emitter.

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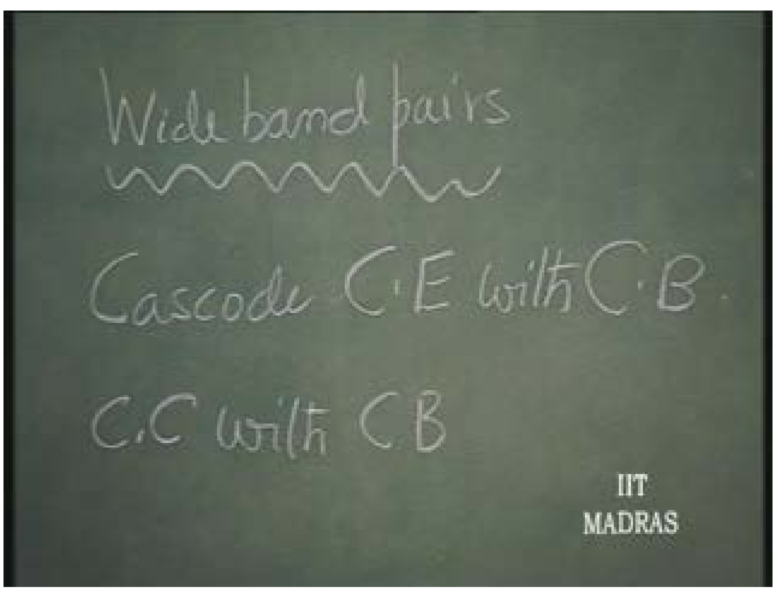

So, common collector - that means collector is grounded with common base. Let us see what happens if V i is applied here at low frequencies. V i. This V i is now going to be applied across r e here and r e here; twice r e. So, the current here, signal current is V i by twice r e. This r e and in series with that common base r e. So, the current in this is going to be V i by twice r e and therefore the voltage across this is going to be V i by twice r e into R c, which is strictly speaking, g m into R c by 2, g m into R c by 2.

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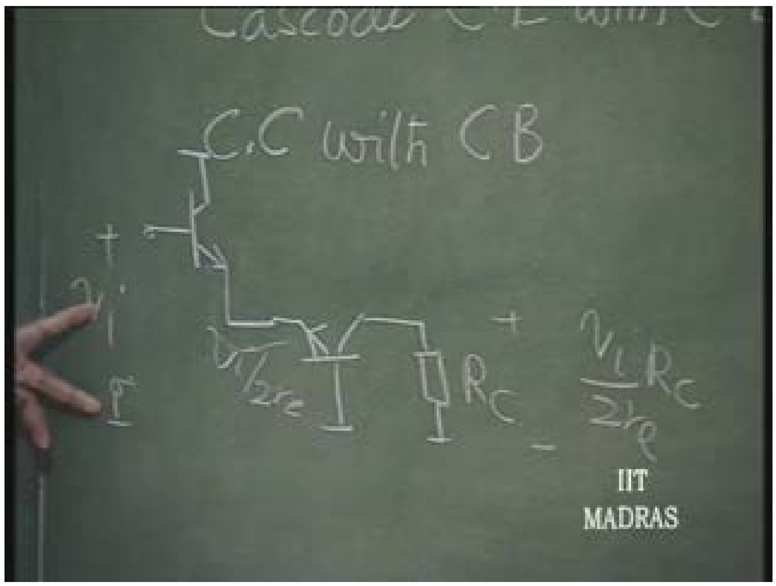

A common collector is a high frequency structure because it is a very good voltage control voltage source. Here, the load is made very nearly equal to the source resistance. So, that is why we have lost in terms of gain by a factor of half. So, the impedance level here is r e. If there is a capacitance, this r e is very small and it is shunted by another r e on the other side. So, r e by 2. So, it is very low. So, the time constant here is very low.

So, the time constant at this intermediate point is very low. This is common base anyway. This is R c and C B dash C. That time constant also is very low. At the input here, normally it is driven by means of a voltage source because it is a voltage control source. So, source impedance is supposed to be very low.

So, capacitance of common collector stage also is very nearly C B dash C because this capacitance does not come into picture much. So, the capacitance into R s which is very low; low time constant, low time constant, low time constant. That means this is a wide band structure.

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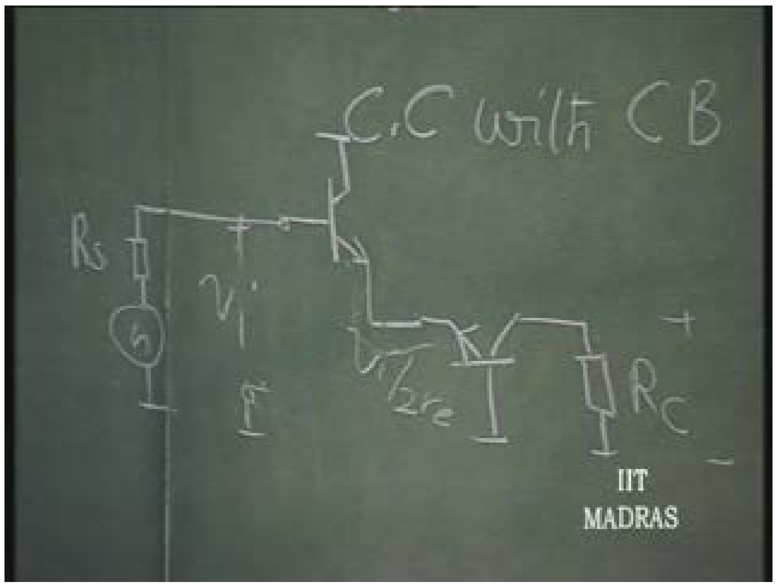

Just like the cascode, this is a wide band structure. Only thing is, it is not equivalent to cascode because this voltage is halved here and appears in the same polarity, because it is a common collector stage and there is no phase difference between this and this. Therefore, there is no phase difference between this and this. So, this is not equivalent to common emitter stage or cascode stage in terms of low frequency gain because there is a phase shift in the case of common emitter as well as cascode stage of 180 degree. That phase shift is not there; but this is a wide band pair.

So, this also can be used for wide band amplifier design. Now, how is it used?

Let us look at the same I C that we had. This collector of, let us say, T 3 is now connected to V C C just like previous situation; and then you can put the load here, R c and now this is strictly being used as a current source. This is a differential amplifier, let us say; but that differential amplifier can be used as a common collector cascaded to common base in the following fashion.

All that, you forget about. So, you will now give the input at this point and you will ground this point to... ground through a capacitor. So, this is acting as common collector. Collector is connected to supply and half the voltage will appear here; and this will act as a common base and across...So, this is going to be strictly used as current source.

So, the same structure that we had discussed earlier can be used as a common collector with common base; not as a cascode, in the following manner. Please remember. This should not be connected to R c. Then it is not common collector. It is going to be common emitter - differential amplifier, it will be. This is not a differential amplifier. This is a common collector stage with common base. So, is that point understood clearly?

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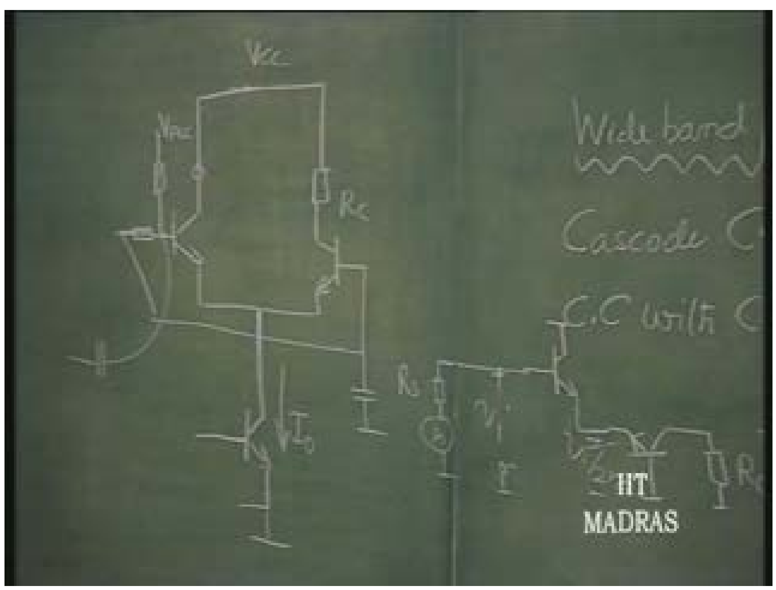

So, this is another wide band structure which can be used; but this does not have that advantage of A G C, etcetera; and Y parameters not varying it, etcetera. Y parameters will vary as I naught varies; and that... therefore if it is a fixed frequency amplifier without requirement of A G C, this stage can be used; wide band structure, for tuned amplifiers. Or, it can be straightaway used for video amplifier where you do not apply the A G C. This A G C terminal is not used. So, you do not connect anything there. So, this is one way of using this as a video amplifier.

Next structure. Common collector with common base, common collector with common emitter. Let us see this.

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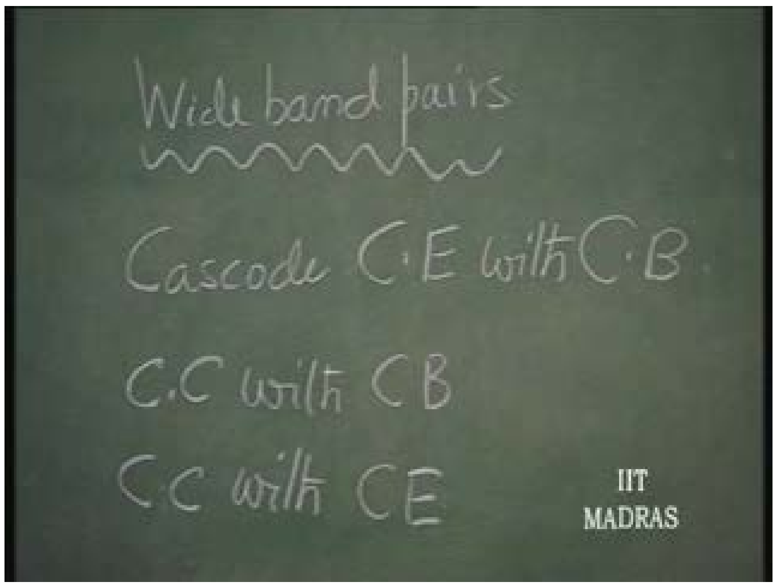

What is the logic behind this? If you just use common emitter, we know that the miller capacitance comes into picture and the miller capacitance will increase the input capacitor; and this input capacitor into input resistance parallel source resistance is what is going to constitute as the time constant.

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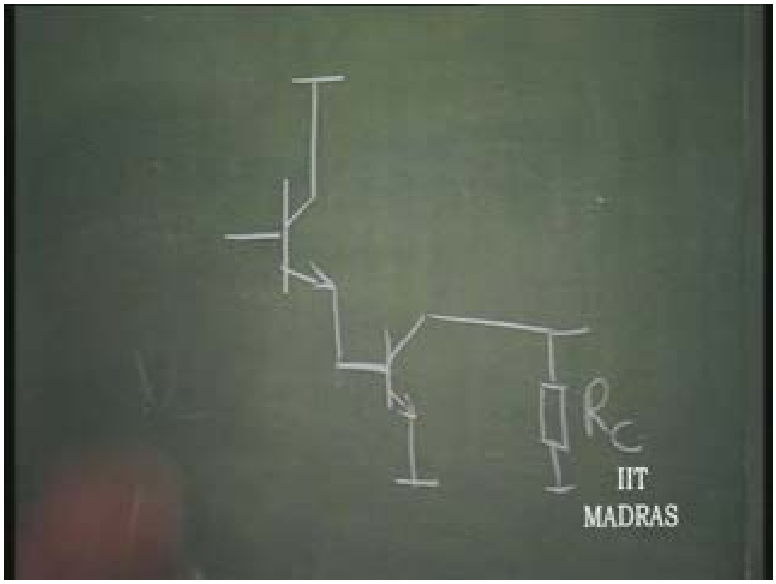

Here, I am putting... if R s is pretty high, let us say; R s is not very low. If I directly connect R s, R s parallel r b dash e is going to be shunting the capacitor. If I put it through a common collector stage, then this is still r b dash e parallel... Now, r e plus R s into 1 minus Alpha is the impedance that is shunting this.

So, the time constant here is decreased. That is, by artificially making it a better source than before, better voltage source than before, by using a common collector structure. So, in case R s is very large, this technique can be adopted in order to use this whole configuration as a wideband structure. The gain here remains the same as that of the common emitter, g m into R c, because the gain from here to here is unity and from here to here it is determined by common emitter amplifier. So, the gain is still minus g m into R c.

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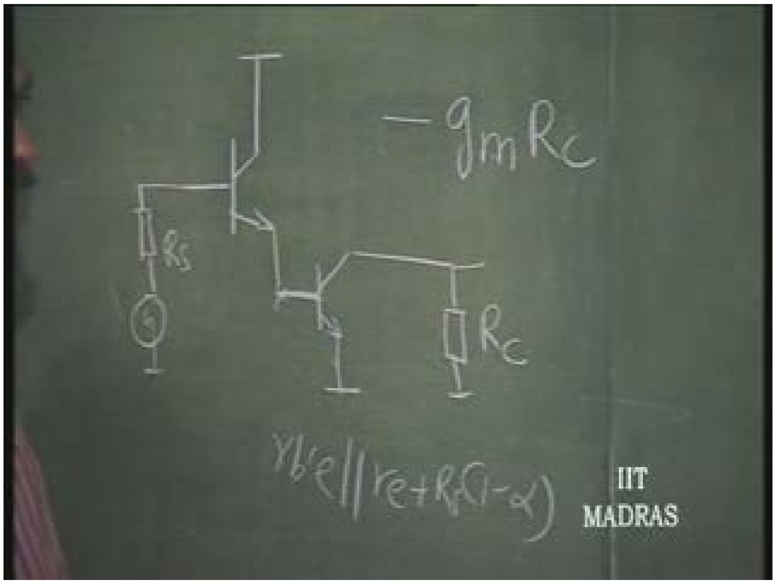

So, for these two things, the gain is remaining the same as common emitter. Here, it is halved. So, this also is wideband pair. All these three wideband pairs can be used for high frequency application of video amplifiers.

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We have, apart from these, negative feedback amplifier stages with local feedback used for wideband applications. This, I have already discussed earlier. This...these stages which are negative feedback stages necessarily must be having simple folds, first first order or second order folds, so that they do not do not go into oscillation.

So, such structures are the following. This we have earlier discussed. That is, Z feedback and Y feedback. This we discussed in detail in negative feedback amplifier. These are wideband structures. This is a voltage controlled current source, voltage controlled current source; and this is a current controlled voltage source. By connecting this like this, it becomes a wideband voltage control voltage source. This also has been discussed earlier. And the gain of this is R F divided by R E. Please refer back in your notes of wideband amplifiers; and this is a wideband amplifier, voltage control voltage source.

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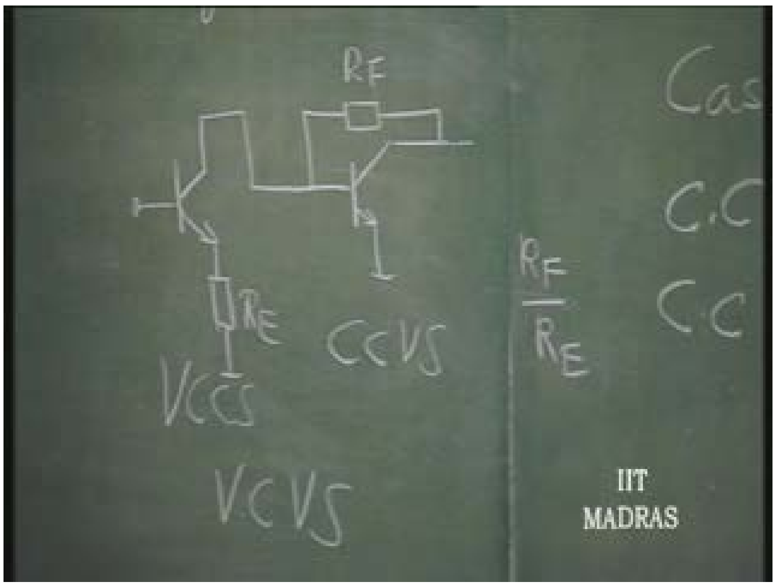

If you want a wideband amplifier, current control current source, then you put this first and then this next. This is a wideband current control current source.

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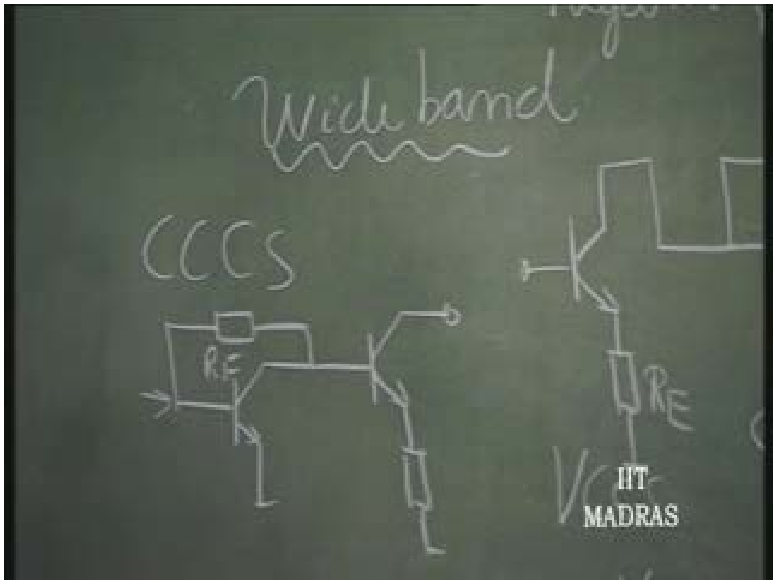

So, you have this individual thing which is acting as a voltage control current source and this individual thing acting as a current control voltage source; and this cascaded together also is a wideband structure which is voltage control voltage source. These two cascaded together will again give you a gain of R F by R E for the current I naught by I i here. This is V naught by V i.

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So, this is going to be current control current source. That is voltage control voltage source; and the individual things are voltage control current source and current control voltage sources, which are wide band structures, which are used all over for video amplifier application. And these I Cs are available as video amplifier I Cs. Only thing is you can convert these structures, for example, into an I C by simply converting this stage into a differential stage. For biasing purposes, this whole I C can be converted into a differential structure.

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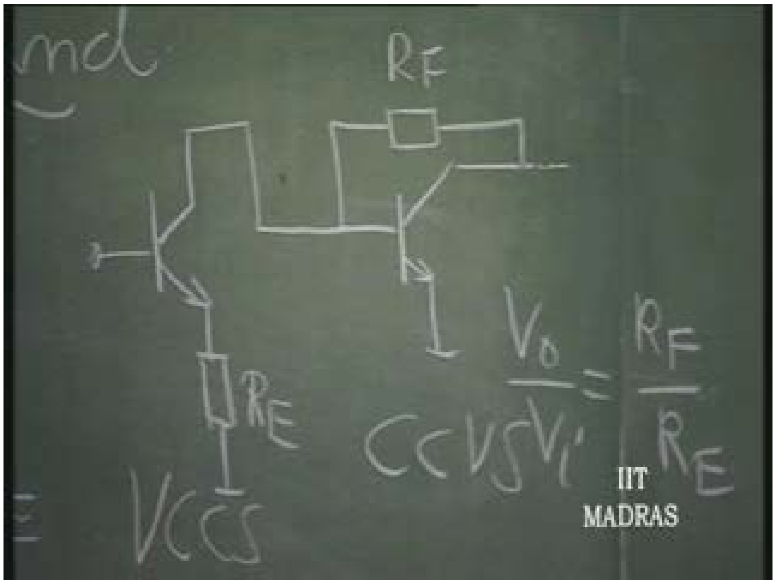

So, I would just want to indicate that for biasing purposes, you have to put a resistance from here and a resistance from here to V C C. So, this is R c 2, this is R c 1; and I just want to indicate how this can be converted into an I C without using capacitors, by pass capacitors, etcetera. So, let us convert this.

I am connecting here R c, 1 R c 2, then V C C. I put another identical stage here R c 2, V i 1, V i 2, R E, 1, 1, 2, 2 - all are identical.

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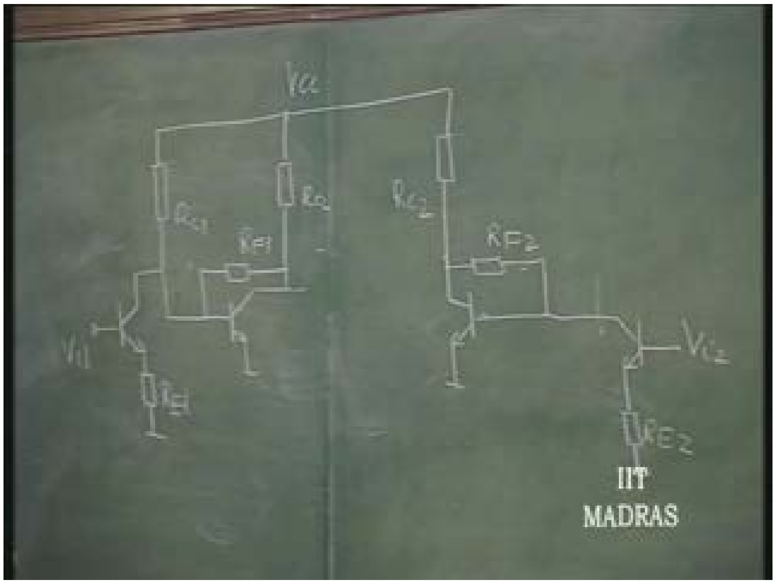

Then I want to convert this into an integrated circuit. The basic principle is whenever you have a symmetric structure like this, the ground, this is the common point, can be lifted; and you can make it go through a current source I naught a, I naught b, minus V E E and plus V C C. So, this becomes a wideband I C.

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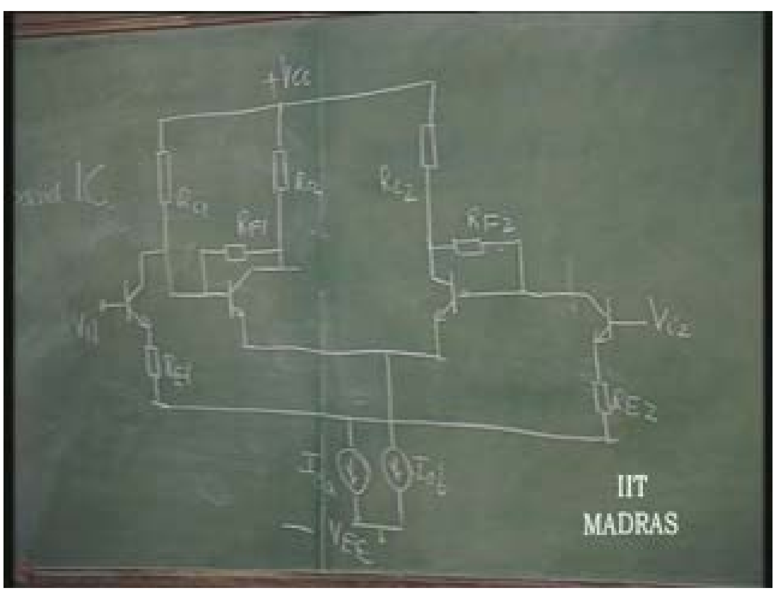

So these current sources once again can be obtained by using current mirror techniques which we have talked about. So again, these can be represented by transistors and it can be obtained by our current period technique or whatever it is. So, zero, zero, R zero 1, R zero 2 - currents can be in terms of the resistor ratios.

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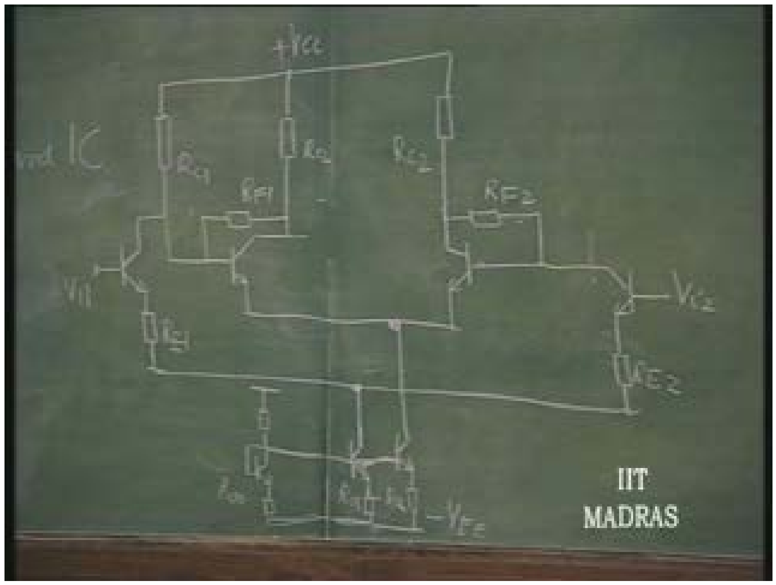

Therefore, this becomes a video amplifier stage usable for very high frequencies of the order of few megahertz. The gain of this, differential gain is going to be R F by R E, R F by R E. If you take the differential output to differential input, this R F 1... R c 2 equal to R c 1, so that these are identical. I think there is one more resistance that is put; these will be R c 2, this will be R c 1.

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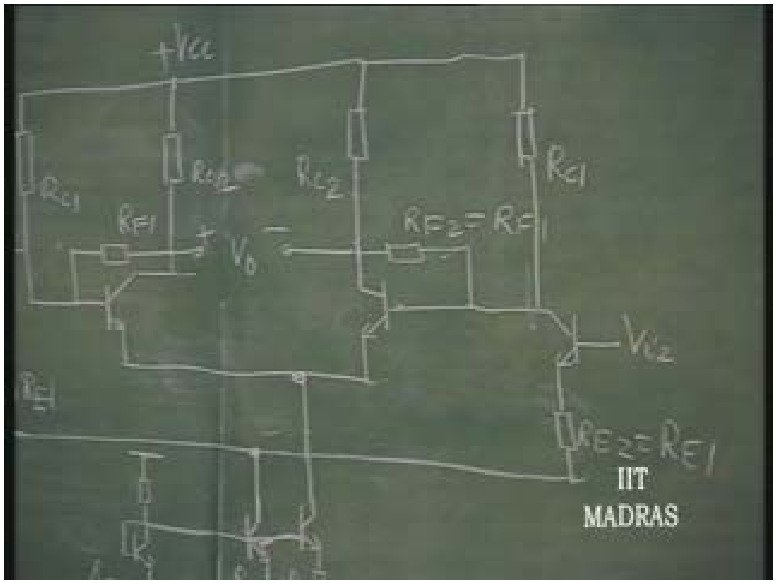

So, this is the symmetric structure which is going to give you a gain of R F 1 by R E, wide band.