Analog Electronic Circuits

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Lecture-81
Current Mirror Circuits (Part- A)

So, dear students welcome back to our online certification course on a Analog Electronic Circuits. Myself Pradip Mandal from E and EC Department of IIT Kharagpur today's topic of discussion it is Current Mirror Circuits.

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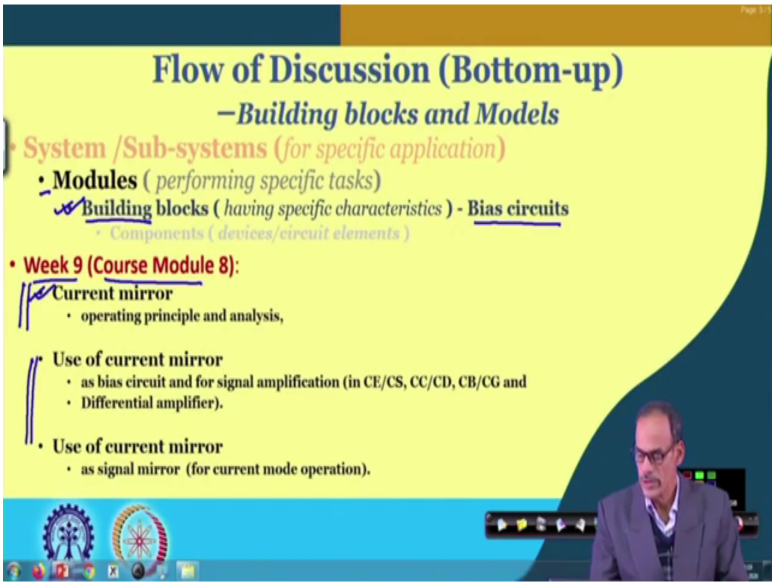

So, according to our overall flow let we see where we are. In fact, we are in module 8. So, we are in module 8 and presently we are in week 9. We are going to talk about current mirror. In fact, this topic it is both it can be considered as building blocks in to be more precise it is bias circuit.

And later on we will see that this building block it well be used in a circuit model. So, we should see this topic it is starting with building blocks, but it is also having a scope to enter into modules. Anyway, so, we are going to talk about the operating principles and analysis of current meter. In the next lectures will be talking about application of current mirror; specifically for amplifier and signal mirroring. So, the concepts will be going to cover here it is.

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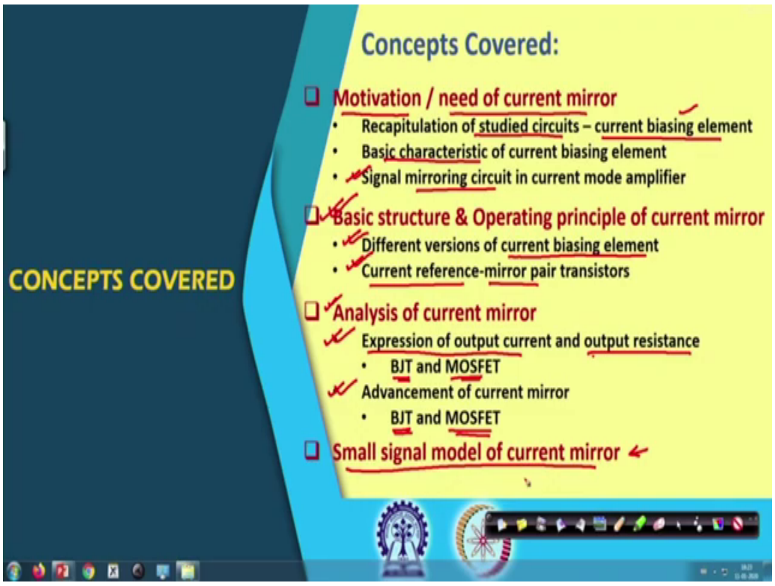

So, here we do have the a enlisted items for today's lecture. We shall start with motivation and a need of current mirror. So, we shall start with whatever the circuit we have studied where we have seen that current biasing elements it helps to improve circuit performance.

And then we shall talk about what are the basic characteristic of a current biasing element, then will be moving to another small discussion highlighting that what is the need of current mirror. In fact, current mirror circuit not only it is useful for using as biasing element, but it also can considered as a buffer circuit in current mode amplifier.

And then after that well be talking about basic structure of a current mirror. In fact, before we entered into the basic structure, we shall talk about the evolution of the current biasing element. And there will see that the evolution leads to current mirror circuit. And then we shall learn on this current mirror. In fact, the current biasing element it consists of a mirror pair and a current reference.

And subsequently well be talking about analysis of current mirror. And it is having basically multiple items here; one is expression, deriving expression of current output current of a current mirror. In terms of the its input current or reference current and also the mirroring ratio. And we shall also talk about the output impedance of the current mirror and we sell cover both BJT as well as MOSFET versions.

And after talking about the basic current mirror circuit and its analysis, we shall talk about the improvement of the basic current mirror to enhance performance. Specifically for improvement of output resistance of the current mirror and there also we shall talk about both BJT and MOS implementation.

We shall also talk about small signal model of current mirror and this is important to when will be going for utilization or current mirror in current amplifier circuit. So, that is the plan. Now, let us a go back and recapitulation what are the circuit, we have studied to motivate ourselves that why we look for current by a single limit.

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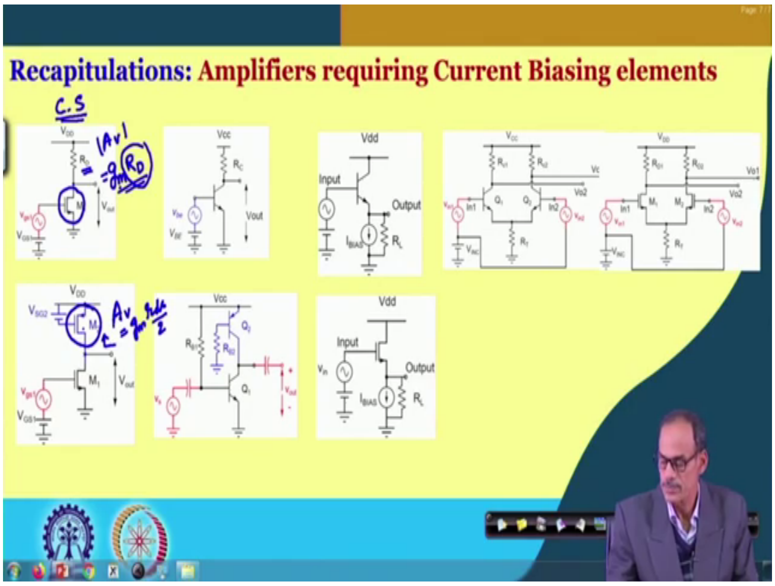

So, here we do have different amplifiers you can see, we do have a common source amplifier, it is constructed by MOS transistor along with its bias register RD connected to the supply voltage VDD. And this circuit it is having a gain small signal gain of gm into RD if I see the magnitude. So, that is the voltage gain and this gain it is not very high particularly since the gm of the transistor it is not so high.

And this gain can be increased by increasing this resistance, but we cannot simply increase this resistance. Instead what we have given a hint that, if we replace this passive element by as a active device M 2, which is offering say much higher resistance looking into its gain. And as a result the voltage gain Av gets increased to gm into rds both the rds in parallel. So, that gives us gm into rds by 2.

So, if we can replace this transistor this registered by a transistor then we can get higher gain. However, if you see we do have this transistor it is having a bias and instead of having this bias, if we use current mirror that makes the circuits more practical more robust against process variation or supply variation. So, that gives us an indication that if we use some current mirror circuit here, then we can enhance the gain. And instead of having single transistor here we can use a current mirror along with it current reference circuit.

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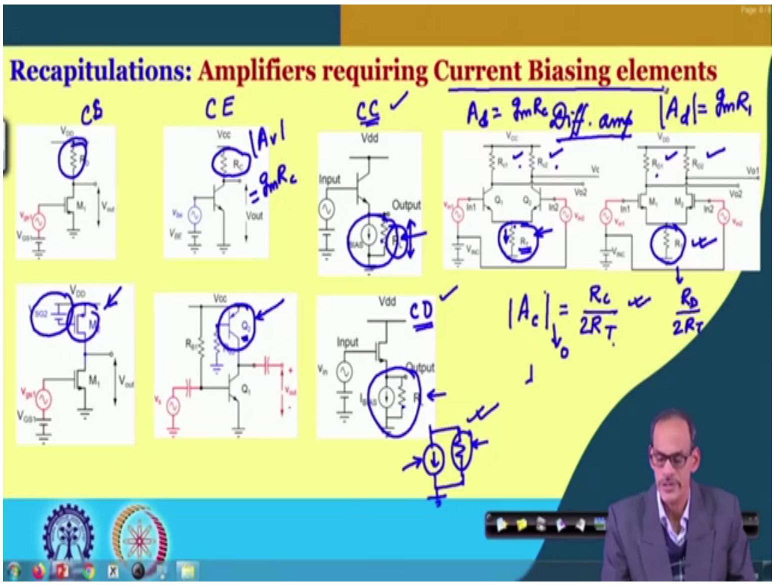

Now, a similar to the common source amplifier here we do have common emitter amplifier here again the load resistance RC; it restricts the gain to gm into RC and so, that is the voltage gain. So, this gain again it can be enhanced by replacing the passive element by one active element here. So, though in this circuit this transistor 2, it is having a typical bias current bias, but of course, this circuit it is sensitive to temperature and beta variation. So, in terms of getting the bias point stability of this circuit, it may be recommended to use a current mirror instead of having simple Q 2 here.

So, likewise if you consider a say a common collector stage CC stage or say common drain stage, where at the for common collector stage at the emitter we prefer to use one current source. And we want this current source it should be almost independent of this output voltage. So, if it is independent of this out voltage output voltage then the performance of this circuits is more towards ideal one.

In other words, this RL whatever RL we are talking here, this RL if it is higher that gives us the circuit performance better; same thing for a common drain amplifier. So, if this RL it is higher that gives the performance of the circuit more towards the ideal situation. So, here once again if we have some implementation of this by a circuit, definitely we can get performance of both common collector and common drain more towards its ideal performance.

So, here again we are landing into a situation that we need the biasing element should be preferably it should be a current source or we can say that it is a current biasing eliminate. So, here we are looking for current biasing element, here also we are looking for current biasing element similarly for this two circuit also.

So, likewise if you consider differential amplifier differential amplifier, here again there is a need of there is a need of biasing element here. If you put a passive register here, that makes the common mode gain magnitude of the common mode gain equals to RC. In this case RC divided by this 2 times RT, we want this gain should be as small as possible ideally it should be going to 0.

Now, here again this equation suggest that if this RT it is higher then we can make it better circuit; namely the common mode gain we can make it lower. But, then if you increase this RT to support required equation current, you may require much higher drop across this registrants. So, just by replacing this passive element by one high resistive elements or high registrants, it will not solve the problem. Instead if you replace this element by a current source like this, then definitely this resistance we can make it a high on the other hand this DC current it may support the required equation current in the circuit.

So, same thing this true for this different cell amplifier also they are also the current common mode gain can be increased. And for this case the common mode gain it is a RD divided by 2 RT. So, if we replace this element by bias circuit and if we make this registrants higher and higher, then definitely we can improve the circuit performance.

In fact, in this circuit we can improve the circuit performance by replacing its load also. So, we same thing here also because the different cell mode gain it is gm into that load resistance. So, similar to common common emitter or common source amplifier, we are as we are replacing this passive element by active element to increase the gain.

So, for this different cell amplifier also if we replace this load registers by current source, then we can improve the different cell mode gain which is having an expiration of gm into RD. So, gm into RD in this case and in this in the BJT version it is different cell mode gain it is gm into RC ok.

So, at least we understand that there is a need of current biasing element, across different amplifier and then of course, whenever you are talking about of current biasing element. Let us try to see what are the basic characteristic we are looking for this bias current biasing element.

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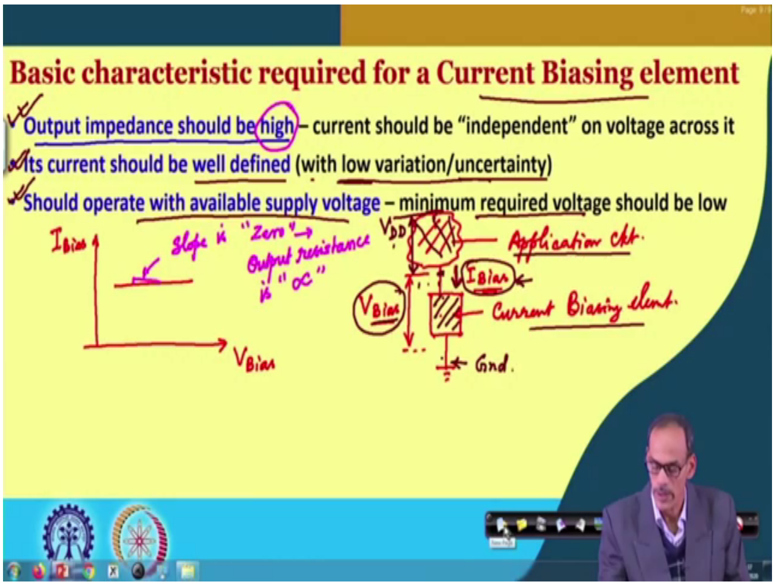

So, here we are highlighting what are the basic characteristic required for current biasing element. First of all the output impedance should be high what does it mean is that, suppose we have say this element whatever the current biasing element and it is having a current flow and then, we do have some application circuit. So, we call this is current biasing elements and this is the application circuit.

Now, we want this current should be well defined by this biasing element; see let we call this is I bias. And we want this I bias should be as independent as possible on the voltage across this we may call this is V bias. So, that is what we want to say that the if this I bias it is independent of this voltage, which means that if we plot the IV characteristic of this biasing element I bias versus V bias. And we want theoretically it should be independent which means it is horizontal line.

In other words, we may say that the slope of this line slope of this line it is zero slope is quote and unquote zero. Or we want resistance you can see output resistance is quote and unquote infinite; practically we want it should be as high as possible. So, if we can achieve this what we will get it is that, in case this application circuit it is defining the voltage at this point.

So, then even though this voltage it may vary based on the application circuit requirement. But if we ensure that this I Bias it is independent of this V Bias then we can say that this bias current of the application circuit it is not getting changed by this voltage variation. So, that is one of the basic requirement. So, this is the first characteristic we will be looking for. So, while will be implementing the biasing element we have to pay good attention to that.

Then second characteristic we are looking for it is the current should be well defined. So, this I Bias should be flowing through this current biasing element, should be well defined; namely I Bias should be easy to implement. And important thing is that variation its variation with respect to whatever the design value. We do have should be as small as possible not only its static value, but even say instant inverse value should be as less dependent on any other variation namely temperature variation or supply variation.

So, we want this current should be a well defined along with this characteristic, the variation should be less or uncertainty of this current bias should be as small as possible. Then the third characteristic we are looking for it is that the this circuit should be operating with available supply voltage, which means that suppose we do have supply voltage here it is say VDD and then we do have ground here.

So, we want this circuit the bias circuit should not be taking too much of this supply reel keeping behind large amount of voltage drop for the application circuit. So, we want this current bias circuit should be operating with a less amount of voltage V Bias across it. So, that is what we said that minimum required voltage across this bias circuit should be as small as possible ok. So, while will be implementing this current bias circuit, we have to pay to this three basic requirements.

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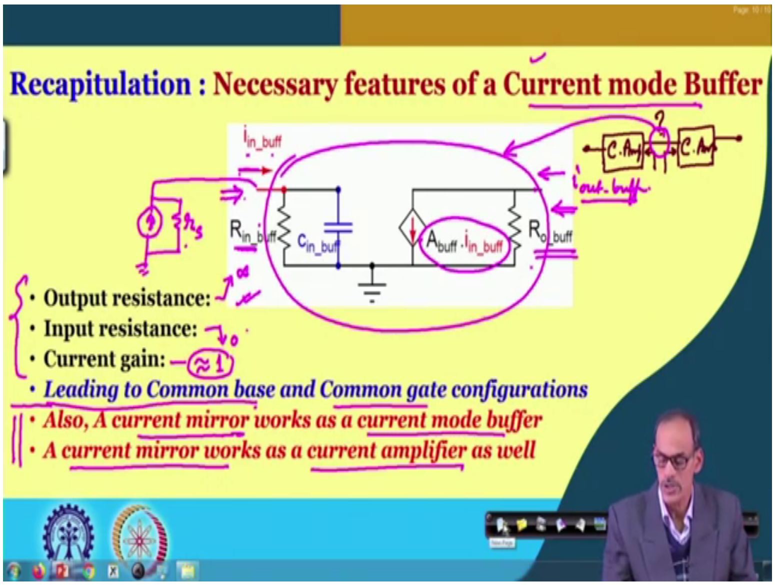

Now, let us see that the basic ok. So, this is the additional information I like to mention that, this current mirror can also be used for current mode amplifier. In fact, this is also recapitulation for us that we have seen if we require one circuit basically one current mode amplifier. If we want to cascade it with another current mode amplifier and the impedance of the previous stage and the next stage if they are not well match. And then if the moment we cascade it may create some loading effect and that may degrade the overall performance of the circuit.

So, what we may require we can place one circuit in between, which supposed to be working as a buffer and this is the model of that buffer. So, this is the model of the buffer here we do have and the input current it is i in buffer. So, this is the internal circuit of on that buffer.

So, it is having input signal it is i buffer and then output signal here it is primarily i out or i out buffer. And this i out buffer ideally it should be equal to a gain times whatever the input current we do have. And we want the input impedance of this circuit, it should be as low as possible on the other hand the output resistance which is R o buffer it should be as high as possible.

So, for current mode buffer we are looking for this input resistance should be as low as possible and output resistance should be as high as possible. So, that the buffer output current it hardly depends on the output voltage; likewise if the input resistance it is input resistance here it is small. Then while we are feeding the current while we are feeding the signal here it should not really depends on whatever the source resistance we do have. So, if the this resistance is small, then entire current it will be getting into the buffer.

And the current gain we may not require much, but at least we should say that attenuation should not be very high. So, even if it is a approximately one that was ok. And this three basic characteristic for current mode buffer leads to the spatial configurations called common base and common gate configuration, based on whether it is implemented in BJT or MOSFET.

So, this is what we have discussed earlier in one of our lecture. And what we are why we are talking this information here is that, current mirror the circuit will be going to discuss today. The current mirror circuit can also work as current mode buffer, which means that the current mirror it is having input impedance low. And also the output resistance it is high and the current gain not only it will be one. In fact, the current gain it can be even higher than 1 ok. So, the that is why I said that, in the second item is that the current mirror it also works as current amplifier.

So, this is an indication that current mirror circuits it is having important role to play, even for current mode amplifier particularly current mode buffer and as current amplifier right. So, that is the motivation of going for this current mirror and current biasing element.

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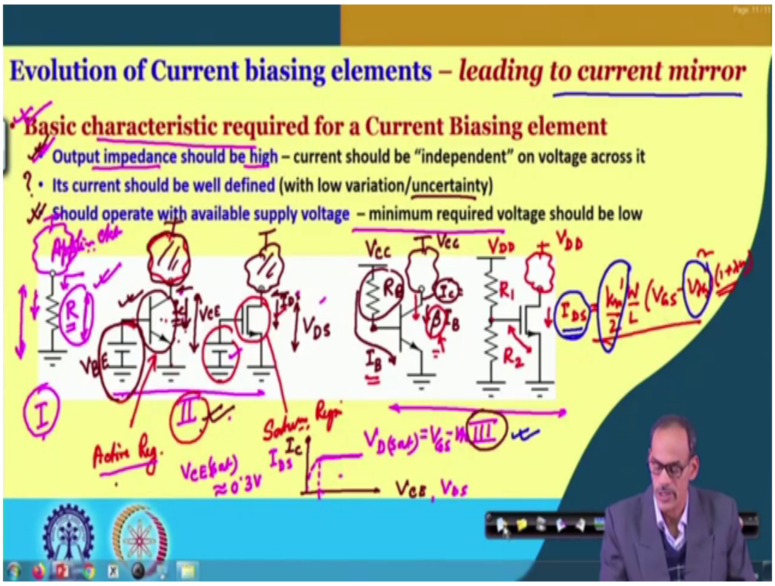

So, let us see the implementation what are the possible implementation we do have. First of all before we talk about the implementation we need to recall the basic characteristic required for this current biasing element. So, here we are enlisting different versions of current mirror or other current biasing element I should not say current mirror it is current biasing element. So, first versions, second versions and then we also have IIIrd versions.

So first one it is the simple register. So, simple register and this bubble indicates that we do have the application circuit connected here. So, we do have the application circuits and, we want the current here it should be well defined. And we also want as we said that it should be well defined the output resistance here it should be high and also we want and that drop across this resistance should be as low as possible.

Now, if you see this basic requirements wise this versions it is not. So, good first of all output resistance it is defined by this resistance itself. And the drop across this resistance if we want it should be as small as possible, then this requirement and this requirement they are conflicting. But based on some restricted application, if we have sufficient amount of headroom across this biasing element available probably we can use this circuit also; but I should say that if we have better option we may go for that.

Now, if you consider the IInd version, we do have a say one BJT or maybe a MOS transistor in MOS transistor, having a meaningful bias here as vbe or vgs. And suppose this transistor it is in active region of operation or if this is the MOS transistor if it is in saturation region. And then if we have the application circuit connected. So, we do have the application circuit here connected, same thing here also we do have the application circuit connected and suppose this application circuit they are defining this voltage and this voltage.

Now, the current flow through this transistor, if it is in active region we know that it is having very low dependency on the V CE voltage. Same thing for this transistor also the IDS current here, it is having very low dependency on the voltage across this element namely vgs.

So, if I plot this IC versus V CE or if I plot the ID IDS or ID versus V DS. If they are in appropriate region of operation we know that the character characteristic it will be quite horizontal or flat. Indicating that it is having good high output impedance. And the minimum required voltage for this case it is V CE sat and for this case it is VD sat typically V CE sat, it is quite low it is around 0.2 or 0.3 volt.

On the other hand VD sat it depends on the VGS. So, that is VGS minus V th. So, it depends on what is the VGS we are applying. But we can see that the minimum voltage we require across this transistor. To keep the transistor in appropriate region of operation it is much lower than what we are expecting for simple register.

So, definitely then the second version is better or I should say superior uh, but still there is a possibility of improvement. Say for example, if you are in this case if you really have to make a precision voltage here to make well defined collector current it may be impractical.

In fact even if you are considering that this VBE it is not or well defined. But based on the temperature variation characteristic of this transistor it may vary. And due to that we may have altogether lot of uncertainties in the collector current. So, I should say the second version, it is satisfying first and third requirement, but not the second one. Second requirement where we are looking for uncertainty in the current value it should be as small as possible.

So, we do have now IIIrd version or IIIrd generation. Here instead of having DC voltage we can put some bias register connected to supply voltage. And then we can have the application circuit that may also be connected to the same supply voltage. So, based on this RB and V CC and V BE we do have IB flowing and this IB in turn it is defining the IC which beta times IB right.

So, the current flow here of course, it can be well defined by this register. So, it is in fact, it is much better to define this current, but still it is a strong function of this parameters particularly the beta of the transistor. So, even if say IB it is remaining constant, but if the beta is changing whether due to replacement of transistor or due to temperature variation then; obviously, this current it will be getting change.

So, likewise here we do have the MOSFET version which is of course, at the gate we do have voltage bias. And we do have potential divider R 1 R 2 which is generating gate voltage from DC supply VDD. And then it is producing a current here based on whatever the VGS we are applying and whatever the dimension we do have and whatever the kn dash we do have right. Keeping the transistor in saturation we can get this current it is kn dash W by L multiplied by VGS minus V th square into 1 plus lambda VDS.

Assuming this one plus lambda VDS part it is very small similar to in this case if you consider early voltage it is high. So, in this case we can say that current is well defined, but again as I said that for this circuit also the current it is definitely, it depends on the device parameter kn dash it also depends on threshold voltage of the device. So, that makes uncertainty of this current also significant.

So, I should say that third version definitely it is much better than the previous two, but still there is a scope to improve the current bias element. Namely to make the current more independent of the you know process variation or supply variation or temperature variation. In fact, that leads to the requirement of current mirror. So, the fourth version or fourth generation of current biasing element is basically a current reference along with a current mirror.

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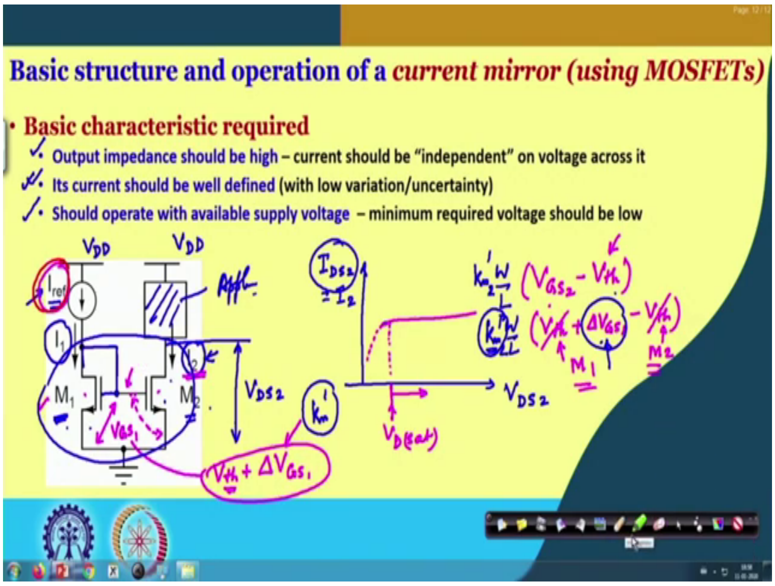

So, here is the basic structure of the fourth version of the current biasing circuit. Now, suppose we do have say two transistors; transistor 1 and transistor 2 and the transistor 1, it is say diode connected, namely its gate it is connected to drain. And let we flow one current call say I reference maybe that is coming from the supply voltage. And let you assume that this current reference is given to us and try to see how this current mirror constructed by M 1 an M 2; it is helping us to define this current here which is a primarily function of this current or this reference current.

Here of course, we do have the application circuit and that application circuit it is connected to VDD. And here we do have the voltage across this transistor we may call this is VDS 2. So, as long as this transistor 2 it is in a saturation region, then we can say that I DS it is which is I DS of transistor 2 in this case that is I 2 which is in fact, the bias current for the application circuit, which is quote and unquote independent of VDS.

So, as long as the device it is in saturation region depending on the value of lambda, we can say that the dependency of this current is very small. Of course, if the VDS is very small going beyond the pushing the transistor beyond saturation region then there will be lot of dependency.

So, as long as the V DS is higher than this VD sat then we can say that it is a good current biasing element. So, how it what is the. So, this is the structure and how it works? Based on this current and based on its dimension, it produces a voltage called V GS 1 and the same V GS we are deploying to transistor 2. So, instead of having independent potential divider. We are generating a voltage at this point for transistor 2 or gate bias of transistor 2, which is also having a term this VGS 1, it is having a term called V th plus some additional element called delta V GS.

So, this voltage since it is having V th inherent within it then whatever the on the voltage we are generating here it is having this V th. So, if I take V GS 2, minus V th definitely this V th and V GS 2 it is VGS 1, which is again it is having V th term plus del V GS 1 and then we do have the second V th.

So, this V th and this V th it is getting cancel making this current mirror making this the current flow through transistor 2. It is independent quote and unquote independent of the threshold voltage of the invertor. Of course, here we are assuming that this V th 1. So, this is for transistor 1 and this is for transistor 2.

So we are assuming V th of the both the transistor they are equal. So, that we have to that we can we can assume that. And in fact, that is a fair assumption particularly for integrated circuit that is it is not so difficult we achieve. On the other hand, whatever the voltage you do have here, it is also having one term kn dash, which is of course, it is so, kn dash of transistor 1.

And so, likewise here whenever we do have the expiration of this current in terms of W nL. So, they are also will be having kn dash and then W by L. So, this part we do have kn dash W by L. In fact, this part it is having kn dash in the denominator and that kn dash and this kn dash they do get cancel each other.

So, that makes these current not only independent of threshold voltage, but also independent of kn dash the process parameter. So, if I assume again this kn dash it is a kn dash of transistor 1 and this kn dash it is kn dash of transistor 2. So, again we are assuming kn dash of both the devices are identical and that is again it is not difficult to achieve. And that makes this current that makes this current mirror a very suitable candidate to make the biasing elements satisfying this particularly the second condition.

And transistor 2 anyway it is satisfying the first and the third condition, we have seen in the third generation of the biasing circuit. So, in summary I should say this is a good current biasing element. But the natural question is that we are looking for of course, we have to have this current reference to make this circuit working.

But I must say for all practical purposes this reference current need not be a very very fancy or very idealistic current references.

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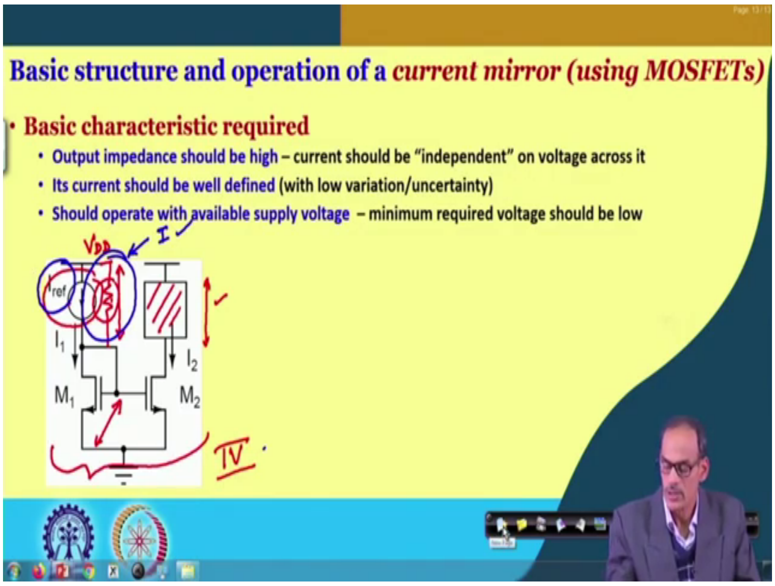

Even if you have a primitive current source, say for example, if you have a simple resistor connected that will also serve the purpose. Because in this case drop across this transistor it is not so big living behind a big amount of a voltage drop available across this registrants.

So, though the application circuit is sitting here and that may require a much higher voltage drop across it; but the drop across this resistance we do it is not getting affected by whatever the requirement of this voltage you do have. So, even a simple resistor it may work for providing this I reference. So, I can say that this circuit it is IVrth generation of current biasing element which is utilizing I st generation or I st version of the current reference.

So, by combining this I st version and this IVrth version and namely the current mirror we are getting a good current biasing element. In case if we have a better option we can go for a current reference. In fact, why we go for current reference.

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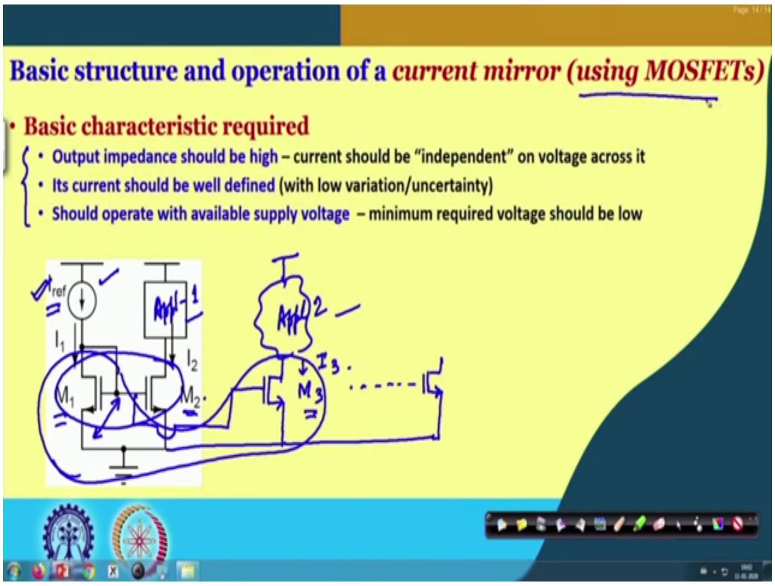

And then we generate another current reference, the logic is if you have only one current reference, which is generating 1 voltage here for transistor 2, that can also be reused to make another current bias. Say you do have transistor 3, that may be connected to another application circuit. So, this application circuit it is different from this one. So, this is application circuit 2 this is application circuit 1.

So, this application and this application circuit all together they are different. But as long as we ensure that M 2, M 3 and M 1 they are similar in nature, then we can say that this current I

3 it is also satisfying all these conditions and so, this I 3 it can be obtained from the same reference current. In fact, you can generate n number of such kind of current reference.

So, if you have one good current reference from that you can have many more current reference you can generate right. So, that is why; that is why we are using current mirror. So, we do have one current mirror here we do have these two together making another current mirror and so and so.

So, this is MOSFET version current mirror. And we can have a BJT counterpart. So, in the next slide we are having the current reference here. So, you can see here it is very similar this circuit is very similar only thing is that we do have Q 1 and Q 2 instead of M 1 and M 2. The here also the collector and base they are connected to make transistor 1 diode connected. And rest of the thing it is very similar and this circuit. Of course, it offers this basic characteristic.

We will be discussing about its analyzes, but before that let me take a short break.

Thank you.