Power Management Integrated Circuits
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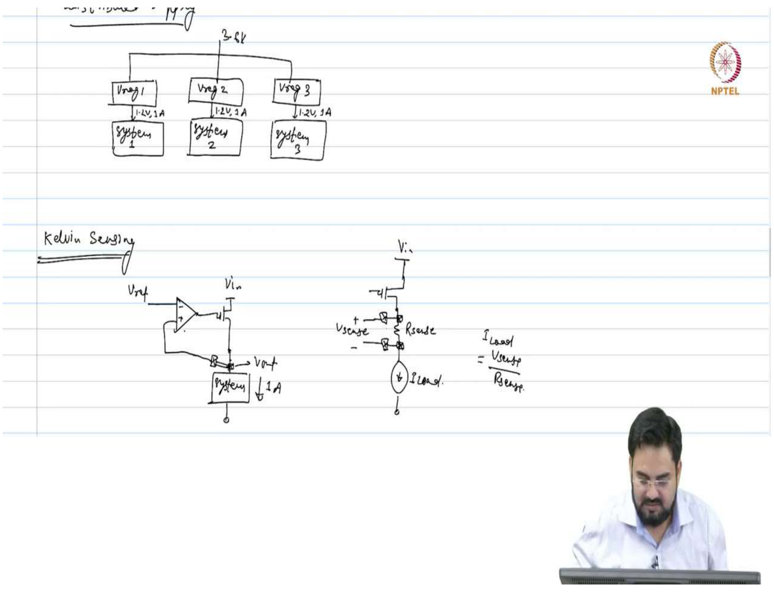
Lecture - 06
Kelvin Sensing, Droop Compensation

<u>Kelvin sensing:</u>

Let’s say I want to sense the load current. So, I will put a series resistor (sense resistor) and take the voltage across that. I know the resistor value, so I can calculate the current.

In the current path if you move the sensing point up or down, your feedback voltage or sense voltage will change. So, whatever the sensing point is just take that out separately. Now, no current is flowing, so it does not matter how long you take it. You can take it closer to your error amplifier also. Sensing point voltage will not change because there is no current flowing into this.

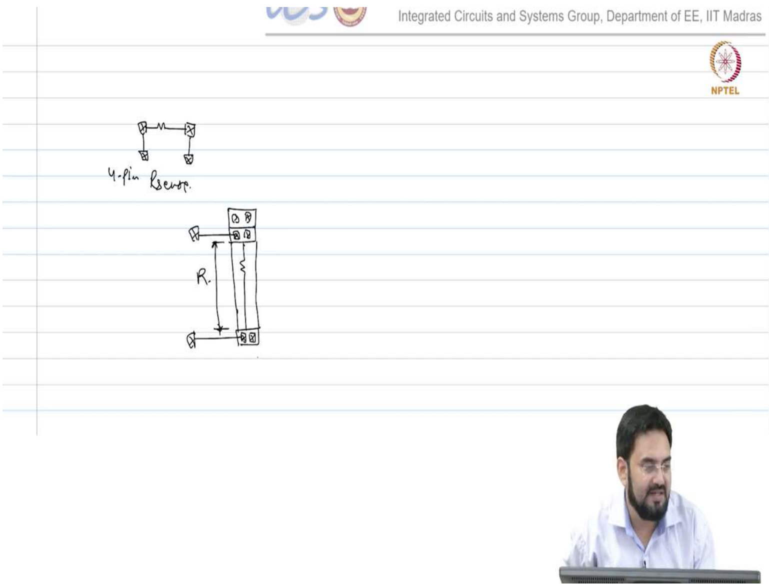
Circuit diagram for current sensing is shown in below figure.



So, $I_{load} = V_{sense}/R_{sense}$. So, we can easily measure V_{sense} and R_{sense} is known because we are putting it externally. And this R_{sense} is usually very accurate resistors, they do not even change with the temperature. And tolerance is very small and these are order of 10s of milliohm, so that you do not lose any power in these resistors. Otherwise your efficiency will get hampered.

So, now you have to put a very accurate resistor but let's say because of these traces you slightly move up or down. I mean you are putting an order of milliohm resistor, but you are not tapping from the right point. In that case the whole purpose of putting these accurate resistors will be nullified.

So, they will provide two extra pins as shown in below figure and they call it sense pins. So, rather than directly connecting to the current path, you sense from these two separate pins and we call it Kelvin sensing. Which means at the point you are sensing there is no current flowing into that. So, most of these accurate sense resistors come with 4 pins and you can look at the data sheet actually.



Let say you are putting on-chip sense resistor. So, in the on-chip your resistor looks as shown in above bottom figure. This is made of a special layer; it could be poly silicone or any diffusion resistor. So, I do not want this R value to change.

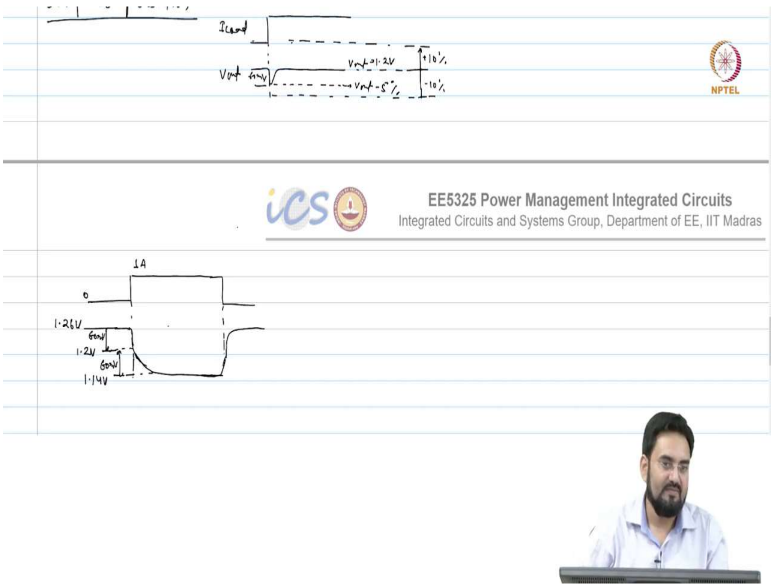
If I am putting this sense resistor on-chip, then you always make sure that you put connection at the contacts directly; do not try to move it up or down because these resistor values are measured between these two contacts and sometimes you do put multiple contacts. But if you put more contacts then current is flowing in this path and those trace resistances will also come into picture. So, you always put the contacts closer to the resistor layer so that you do not have any additional IR drop.

Droop compensation:

Droop is nothing but the undershoot or overshoot which you have due to line transient or load transient. Let's say you have designed your regulator and you are not able to achieve undershoot or overshoot better than 5% and your requirement gets tighter due to some reason or you want to have enough margin for other errors. So, this is usually meant for that.

So, we are applying load as shown in below figure and your output is regulating at 1.2 V. And we want output to be regulated within ±10% in all conditions including your inaccuracy everything.

Due to some reason let's say you have put a smaller output capacitor and due to some reason this V_{out} dips closer to 10%, then you hardly have any margin in that case. What can we do to make sure that output does not get closer to 10% or to increase this margin? So, my system says that as long as you are within ±10% it is fine. So, when I do not have load then it is possible that my V_{out} overshoot this margin.



So, when you do not have any load if I regulate my output at 1.26 V (5% higher) instead of 1.2 V then if load comes then it dips and comes back to 1.2 V as shown in above figure.

So, let's say the undershoot goes to 60 mV, then it will go to 1.2 V. So, to the system it will look like a 0 V undershoot because you are not going below that and even if you go 60 mV further it is only 5% extra. So, you never go closer to 10% and you have enough margin. But shall I get back again to 1.26 V after my load is applied?

If you come back to 1.26 V, then you are making overshoot worse in that case and you are reducing the margin because that side is now squeezed and you are getting closer to 10% boundary. So, now instead of 10% you have only 5% margin left. So, when I have a load; instead of regulating at 1.26 V, I will regulate at 1.14 V.

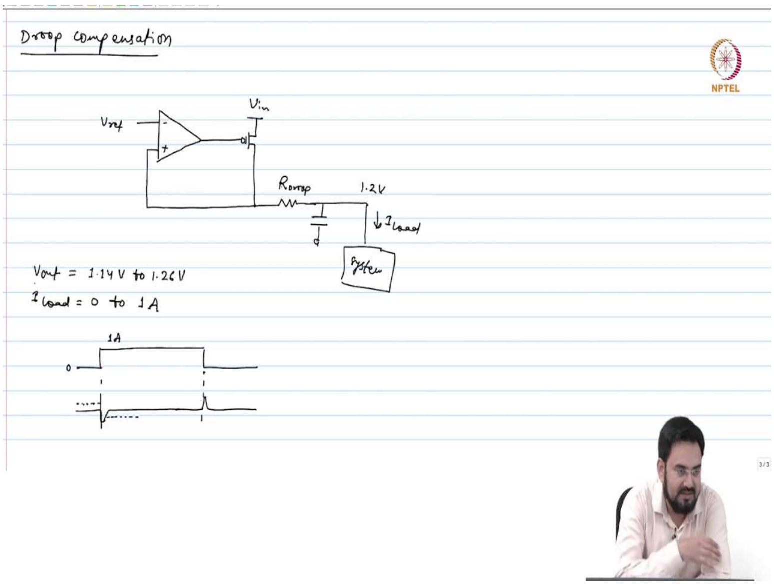
Now, if you release the load then output voltage will try to overshoot and come back, then again you regulate at 1.26 V. And usually this window is regulated with the load. You cannot keep this window fixed because for the maximum load you want to choose the maximum value and for smaller load you do not want to stretch this to 60 mV. So, first you see what is the maximum load and define how much window you want to have for that.

Let's say 1 A is my max load and I want to have ± 60 mV window and it has to reduce with the lower current. So, let's say for 500 mA you will make it ± 30 mV, which means this window should be a function of your load current. So, you sense the load current and change your V_{ref} in such a way that depending upon the load (high load or no load) you decide, whether it should be above 1.2 V or below 1.2 V. This is called droop compensation and a lot of time it is used in your system.

Now, go back to your remote sensing. Will remote sensing make an automatic droop compensation? So, you have a trace resistance R_t. When you apply the load your output voltage will dip and that is what you are doing in droop compensation. So, if your system is placed remotely and you have a trace resistance R_t, then this droop compensation will automatically be there. If you want to make the droop compensation, then making remote feedback does not make any sense. But, one thing you have to make sure that your IR drop across the trace resistance should not be large enough so that you hit one of the boundaries. If you make sure that your trace resistance is smaller and it's within your limit, then you can use it. Otherwise you will have to deliberately do it by controlling the V_{ref}.

There are two ways: You can put a series resistor at the output or utilize the trace resistance and you will automatically get that or you control the V_{ref}. The advantage with controlling the V_{ref} is that you do not have any additional losses because putting the series resistor means I^2R loss will be there. That is the only drawback but by default if you have trace resistance there; then you do not have any choice, you just try to utilize the same for this purpose.

So, how do you usually implement this? One way I talked about you can put a series resistor R_{droop} as shown in below figure.



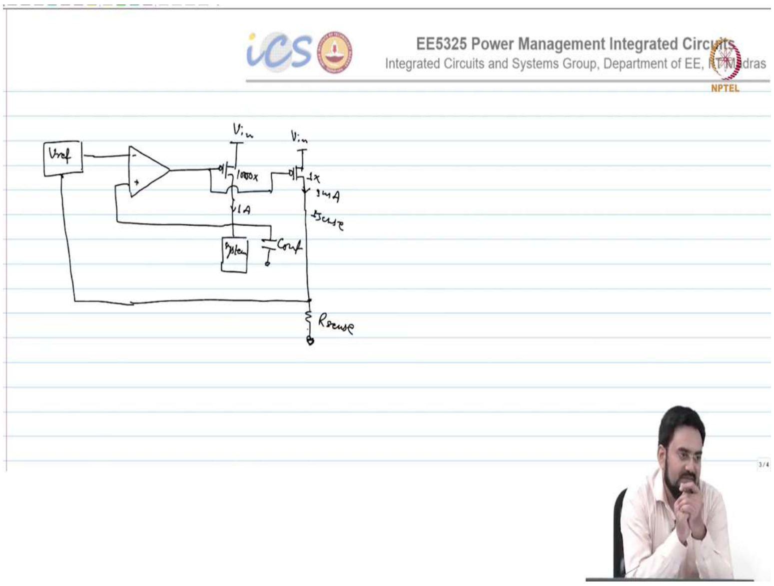
Let's say regulator output voltage is 1.2 V and I want V_{out} to be 1.14 V to 1.26 V with I_{load} equal to 0 to 1 A. So, in order to get droop compensation in both the directions, you will regulate at 1.2 V when your load current is 500 mA. And if you have more than 500 mA then it will be less than 1.2 V.

Ideally when you have the load you want output always to be higher because you know that when you apply the load your output is going to dip. So, at no load your output should be at 1.26 V, which means at no load V_{ref} should be at 1.26 V. When the load is increasing, IR drop will increase and V_{out} will start going low. So, basically V_{out} depends on your load. This is the one way you can implement. But it will have losses because of R_{droop}.

Other way is by changing the V_{ref}. We prefer to control the V_{ref} itself rather than using this series resistor because we talked about if we have a trace resistor, we automatically get droop compensation, but that is not precise control because your R is not fixed and it may be anything. So, more precise way to do this droop compensation is to change the V_{ref} rather than using this R_{droop}.

Since you are not depending on IR drop, so you can put your regulator closer to your system to minimize that IR drop. So, you either use a remote feedback or put your regulator closest to the system. So, how can we change the V_{ref}?

Student: We need to know whether load is applied or not.



So, you need to sense the current. In order to sense current, we use current mirror as shown in above figure. Let's 1 A current is flowing into the power FET and I want to sense 1 A, but I do not want to put the same size of the transistor to sense that. If I do that I will be losing a lot of area and a lot of power also. So, we use scaled down version of that. So, let's say if power FET is a 1000x then this is only 1x.

So, if 1 A is flowing in power FET then only 1 mA will be flowing in current mirror. Now you can sense the current and based on that you basically control this V_{ref}. You can dump the current into a resistor and use the voltage across that resistor to control your V_{ref} . This V_{ref} is mainly generated by using a band gap voltage reference. You have to take this voltage and add or subtract the same in order to get $V_{ref} + \Delta V$ or $V_{ref} - \Delta V$ depending upon whether load is there or not.