Analog Circuits and Systems through SPICE Simulation

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Lecture – 53

Welcome back, we are going to look into the some of the non idealities that we have in the front end amplifier. So, far we have discussed the offset concept with respect to the comparator and we looked into the possible solutions that can address that issue. Likewise of course, in front end amplifier we have more severe constraints, we have the constrains related to the noise; along with that if you have mismatch in the circuit; if you are having offset in the amplifier, how does that affect the characteristics of the overall feedback amplifier that we have built.

Along with that we have discussed in the beginning that the signal specification is going to it can have a very wide fluctuation in the baseline. So, if you remember the discussion in the beginning when we are trying to set the specification the front end amplifier.

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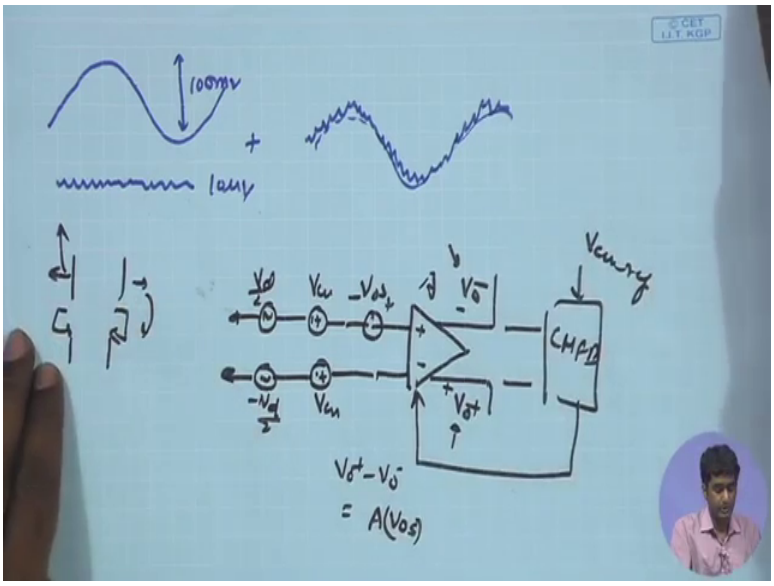

We notice that the baseline can have a huge swing few hundreds of milli volts and on top of that, you have the tiny signal setting which is maybe 10 micro volt or 100 micro volts.

So, the actual signal that you are getting is basically the desired signal; the small peak to peak desired signal, sitting on a highly undesired large undesired signal which seems to be rejected. So, this is another non ideality; this is coming from a signal part that also needs to be addressed. Before that we also need to check; what is the issue with the offset of the front in amplifier itself, whatever design we have made whether it is able to cope with the offset of the front end amplifier itself.

So, whatever concept we have applied for offset consideration in the comparator; we are going to look into the same scheme over here and try to see whether our biasing arrangement and the feedback arrangement; that we have for the fully differential operation, whether it is giving us appropriate offset cancellation.

So, remember initially if you do not have the resistive feedback and suppose you have some DC bias; on the top of that DC bias, you have some AC signal coming in. So, you have some Vcm and then you have the AC signal Vd by 2. And likewise on the other side, you have another Vcm the common mode and then you have minus Vd by 2 and these two are applied to the positive and negative terminals and then one of them is having offset.

So, suppose you are having a V offset; if you do not have the feedback from output to the input, you have controlled the output DC point using common mode feedback. So, this is this is controlled using CMFB circuit, so it is adjusting the common mode at the output minus of V out 1 or V out plus plus V out minus by 2; will be equal to whatever reference common mode you have; Vcm ref.

So, if I say Vo plus and this is Vo minus; then I know that Vo plus plus Vo minus by 2 will be equal to the Vcm ref, this circuit will try to make sure that it is true. But the individual levels Vo plus and Vo minus, we are not sure about that; if this is not having the resistive feedback. And then if I assume that; suppose I try to see first of all what is happening when the input is set to 0, that is how we calculate or observe the effect of offset.

So, we set the input signal to 0; apply the same DC level at both the inputs and then try to see what is the output. Ideally if the transistors are fully matched, if you are applying the same DC level; vc and Vcm to both the inputs, the output DC level will also be exactly same equal to the common mode level, but if there is a V offset coming in over here and you have the gain A, the Vo plus minus Vo minus will be different and then we can say that Vo plus minus; Vo minus will be equal to A times V offset. Because this is in that case the V offset is going to be effective differential signal between the two inputs.

And the common mode circuit can at the mess make sure that the Vo plus plus; Vo minus by 2 is equal to the Vcm ref. But the Vo plus and the Vo minus will be different by a times V offset. And if we have a offset of even 1 milli volt under that condition, you are having a gain; the overall closed loop again of this circuit pretty large say 10 to power of 4; it can completely saturate the amplifier.

Even if you are having a feedback amplifier, where you have the feedback circuitry, suppose resistive feedback or capacitive feedback connected; if I assume resistive feedback, in that case once again the offset voltage is over here can create large deviation in output signal and the outputs can saturate to high or low value even for a small offset voltage over here.

So, in case we go for the normal operation; suppose that we have a resistive feedback and then we are forcing the output common mode to be having some value, a mismatch over here can; suppose you are having a input independent bias for the input with respect to the output and under that condition any mismatch in the input side or the mismatch in the devices, in the differential amplifier side; it can create mismatch or significant mismatch in the output levels; for the same DC level the output will be very different.

And despite having same common mode, the actual DC levels at the two drains of the diff amp will be very different and that can lead saturation on the output. Because you expected that both the output of the diff amp or the output stage; if I will say; so, will be close to Vdd by 2, but rather than being at Vdd by 2; it is you know already very far away from Vdd by 2; one is closer to ground and other one is closer to vd and as a result the signal swing that you can have is already very much minimized, you cannot go significantly higher or lower.

Because one side is; and the DC condition under 0 input one side is approaching close to Vdd; another side is approaching close to ground, which is not very desirable characteristics. Therefore, independent control of the output common mode and input common mode can create these issues and if we do that once again we may have to go for auto zeroing and those kind of techniques to take care of this offset voltage. So, that the offset is compensated and we are able to cancel it out.

But once again if you apply auto (Refer Time: 06:42) in the front end amplifier itself and you have so much switching noise coming from those transistors. They can once again aggravate the noise considerations, they can make the noise worse. As a result, the resistive feedback that we have for the biasing; we can see that that itself can help us in mitigating the effect of offset to good extent. Let us see what how does it that help us.

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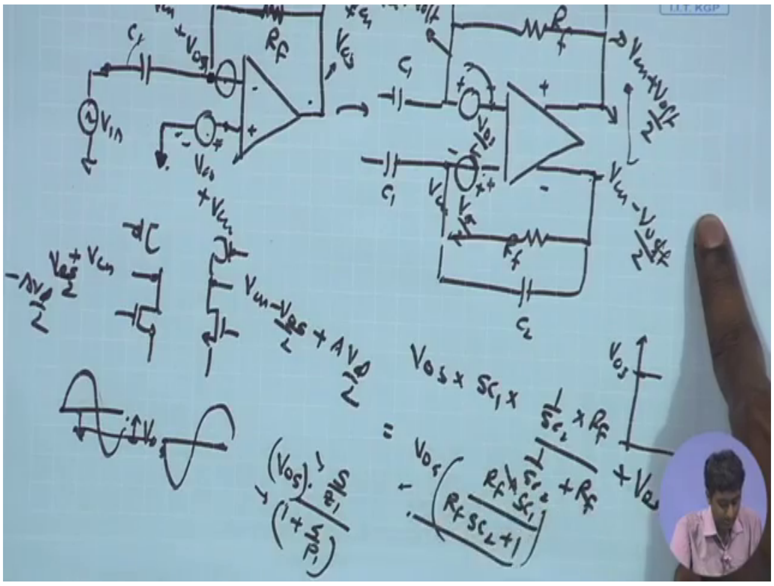

So, suppose you are having let us look at the single ended version, so if you are having the single ended version; you are having large resistor RF that we saw in our example connected over here. And you are having the V offset; plus minus and you are having negative feedback and then of course, you have the capacitors which are implementing the gain having C 1; C 2.

And on the other side; suppose you are having a DC potential of course, I am having a single ended version and if I try to see what is the effect of this particular offset on the output in presence of the RF and C 1 and C 2. Or we can correspondingly look at the fully differential version also and try to see that if there is an offset what is the effect on the fully differential output; we can keep the offset at any point and then you have the corresponding capacitive feedback.

Now, if I look at this circuit; 0 plus V offset, so this is a DC potential means from Vcm. So, of course AC point view; we set it to 0 and this is 0 plus V offset; as a result this is also going to be the same point, V offset. And if I look at DC; DC remember the capacitors do not have any DC path. So, if I look at the DC biasing they are not going to play any role. And if this is set to V offset, we can say that since there is no DC path in the capacitor; there is no current flow, the output should automatically be also equal to V offset.

If I add DC value; suppose in the actual circuit of course, you have some DC potential over here. So, V offset plus say Vcm; some DC potential with the help of which you have biased the input device. So, that Vcm plus V offset comes here and therefore you are going to have that Vcm plus V offset here and then Vcm plus V offset here. So, as compared to Vcm at the output point, you just have Vcm plus V offset. So, it is not amplified V offset is not amplified in this configuration; whatever offset voltage is present; it is as it is translated to the output.

So, because of this resistive feedback; the output and the input DC potentials are becoming same. As a result you do not have amplification at the DC, because offset; I can assume this offset to be very slowly varying even if it is very slow little bit with temperature, with aging of the device, but it is much slower. I can assume this is a DC and therefore, it is not going to pass through any of these capacitors and ever; whatever DC potential V offset is appearing over here; V offset plus Vcm appears here and again that DC potential is carried on from to the output.

So, there is no current through this capacitor; as the result the output DC potential and this particular point will be same. Same can be said about this potential; so, if I assume that the output is controlled, you have Vcm at the output and as a result the differential; the overall amplifier output common mode is going to be Vcm. So, I can assume that suppose the output this particular output is said to be Vcm, as a result once again if I see because this resistive feedback; you do not have any AC current, any DC current through this capacitor; this has to be once again Vcm.

However, if I take the polarity of the V offset in this fashion; this again has to be Vcm and this therefore, becomes Vcm plus V offset and as a result once again this particular terminal has to be Vcm plus V offset. And effectively if I have the common mode feedback available, it will try to make sure that the common mode voltage is same and therefore, it will push it to V offset by 2 and minus V offset by 2. So, there will be a differential swing and in that case; I can model the V offset also as plus minus V offset by 2 or this two terminals. So, I can model this as V offset by 2 over here and minus plus V offset by 2 over here.

So, this is just a way of modeling because I can represent the V offset by 2 over here as well. So, effectively differential offset between the two terminals remains same; so, if I look at the open loop amplifier behaviour plus minus, the effective difference between the two terminals remains same; which is equal to V offset by 2 and plus V offset by 2; minus V offset by 2 and under that condition, the output DC potential will be once again set the common mode feedback will force that the output DC potentials remain similar or close to the Vcm and therefore, it will try to push this to Vcm plus V offset by 2; Vcm minus V offset by 2.

Therefore the difference between the outputs will not be much larger than the V offset. So, you have the difference just given by the V offset; corresponding to the effective input referred offset of the amplifier. So, in case of resistive feedback; the offset at the or the difference between the output is just equal to the offset voltage and therefore, it is not magnifying that offset in saturating the amplifier.

So, this resistive feedback in fact, is helping us in taking care of the offset also and we can look at the transfer function also; if you look at the frequency domain transfer function part, the feedback there also you can see that ultimately the effect of offset is getting, it is only passing at the DC and the because of frequency response of this capacitor; anyway the signal response is not affected by this offset.

So, for the signal response once again we have this at the DC source, so I can forget about this DC source and look at applied signal over here V in and find out the output signal because of this V in and then superimpose it on the effect of V offset. So, if you have V offset and V in together, then because of V offset you are having the output DC level shifted to V offset plus Vcm. So, slightly different as compared to Vcm; you have V offset plus Vcm.

So, if this few tens of milli volts will be 20, 30 milli volt then only difference is that rather than Vdd by 2; you may be having Vdd by 2 plus 10, 20 milli volt. Whereas, if you are having the V in applied over here; the output DC point on the two terminals are slightly different rather than exactly being Vdd by 2; one of them is Vdd by 2; plus 10 milli volt, another one is Vdd by 2 minus 10 milli volt. And then the AC signal is going to superimpose on those two different DC levels..

So, on the point of view of DC; what I can say is that two nodes, the two output nodes final output; suppose in common source stage, these voltages rather than being exactly as Vcm, this will be Vcm plus V offset by 2 and this Vcm minus V offset by 2 and then you have the AC signal coming in. So, on the top of that you have; A times Vd by 2 and minus A times Vd by 2; where a is a gain differential gain from input to output, so this will be the picture.

So, DC levels slightly shifting on the two outputs by V offset and then you have the fully differential operation on the two outputs. So, if you having this resistive feedback then only difference is that the DC level will be shifted by a little bit on both sides; not exactly same and then you can have the AC signal on the top of this. And if the offset is few milli volts, a few tens of milli volts, 50 milli volt is also ok means we need not worry so much about the 50 milli volt of DC shift in the output levels.

There is not important concern because as long as the shift is sufficiently small as compared to the maximum swing you have available, it may not be a very important concern. Maximum swing that is available is say 1 volt peak to peak or larger than that; in case of op amp, we have seen that you can go all the way to 2 volt peak to peak. As compared to that, this shift can be few tens of millions 20, 30, 40 milli volt.

So, if that is within this limit we can tolerate that much shift; we may not go for additional steps for cancelling the offset in the front end amplifier. Because only thing it is doing here in the resistive feedback configuration, it is leading to some shift in the output DC levels and that may be a few tens of milli volts; as compared to the whole swing smaller fraction. As a result, we are not going to apply any additional offset cancellation or auto (Refer Time: 16:04) scheme for these front end amplifiers to cancel the offset in the mean amplifier.

So, we can see that; if you have the RF present, the offset effect is automatically taken care of. For the AC analysis that just like we do the transfer function analysis, we can also do the same transaction analysis for the V offset also. And we have the same high pass filter response coming in and as a result, we know that the offset is the DC value and the offset value will not be passed on to the signal.

So, for example, if I want to see the overall transfer function with respect to V offset; so I can say this is the V offset and with respect to that; if I assume this signal over here is 0 and we have the V offset over here, then we have V offset divided times SC 1 is the current flowing to this one and that multiplied by the Z of this; which is basically 1 upon SC 2; parallel RF upon 1 upon SC 2 parallel plus RF coming in.

This is the output because of the V offset only and as a result, we have once again V offset RF; SC 1 upon RF; SC 2 plus 1; this is the output coming and once again we have the two poles S, we have overall output because of V offset given by S upon; you can say Z 1 and you have 1 plus S upon; P 1 and out of this which one is smaller?

So, if I say RF C 1; so RF C 1, the 0; Z 1 is denoted by the C 1 component and we know that C 1 is going to be larger. Therefore, the RF 1; upon RF; C 1 is going to like towards lower frequency; whereas, the second component RF, C 2; that is C 2 is lower value just to have a gain, we know that C 1, C 2 ratio is greater than 1; C two is smaller.

Therefore the 1 upon RF; C 2 component is going to like towards higher frequency loop. So P 1 is going to like towards higher frequency, another result the overall transfer function for the offset to the output is of course, as we have S approaching 0; then the output is just V offset and we know that this signal itself is only DC and then as we go towards; when we approach say S equal to Z 1; when your S is say much greater than. So, when your S is much greater than P 1; then once again you are having this component coming in and as a result just a minute.

So, at S equal to 0; you will have the DC value just a minute; so, you have the S 1; Z 1 is upon P 1. So, as the S approaches 0 and therefore, you are having the just a minute there is some (Refer Time: 19:25) S. So, I did the V offset times SC 1 and divided by the parallel combination; this and as the result you have SC 2 1 this; and as a result if you are having S upon C 1 and looking at the DC value where S is going much lower than (Refer Time: 19:52) it is just a minute.

So, if I look at higher frequencies then of course, this is going to be; so, what I am trying to do is; that means, as a function of V offset; which is the DC quantity trying to see how the output is going to vary. So, if I look at omega equal to 0; there I have the offset propagating as it is, but let me see why it is not coming here. So, V offset times SC 1 and feedback path and therefore, we have SC 2 and as a result if I put a omega equal to 0 here; you are getting this 0.

Let me see what was the issue; any error that you can see, RF this is the current and that will multiplied by the Z and this is what I have written and as a result I have RF; SC 2 coming in and SC one times RF; 1 plus SC; 2 times RF and this is the output as a function of V offset and mean is 0. So, as it tending to 0; what am I getting output equal to let me see.

So, if this is the V offset and I have V off means whatever this has to be V offset and as a result, the output has to be equal to V off set, but what is let me check this. So, why this transfer function is coming one sorry.

Student: one the other (Refer Time: 21:49) one plus (Refer Time: 21:50)

Sorry is.

Student: (Refer Time: 21:54)

No; so, here yes. So, if I see the V offset over here and the potential over here is V offset times SC 1; this is the current and then you have sorry yes; you have the V offset and plus this sorry.

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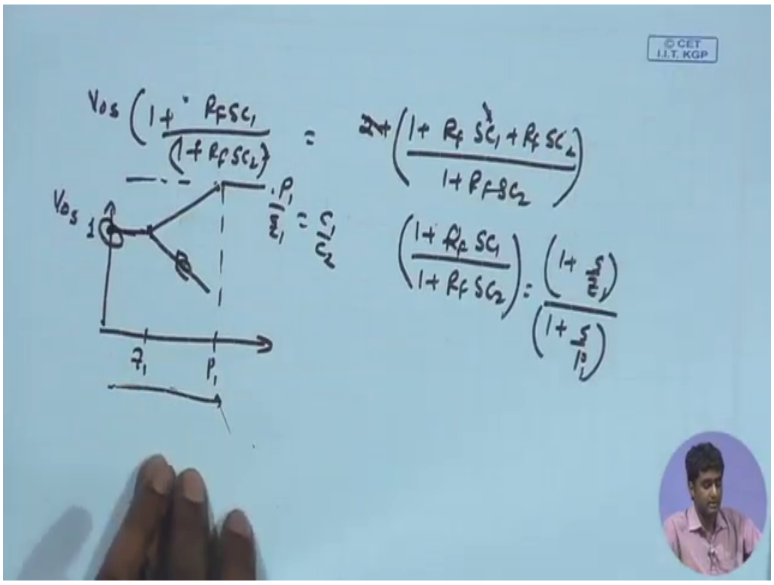

So, you have the overall sum of the function coming as 1 plus; you have the overall function coming as V offset times; 1 plus RF; SC 1 upon 1 plus RF; SC 1 plus 1 and as a result and the denominator I get 2 plus or rather 1 plus RF; SC 1 plus RF; SC 2 upon 1 plus RF; SC 2.

And here I know that my C 2 is going to be much smaller as compared to C 1; I can ignore that, 1 plus RF; SC 1 upon 1 plus RF; SC 2 and then the corresponding another function is going to be; simply if I look at the values as I said this is 1 plus; S upon Z 1 and or Z 1 plus S upon P. So, if I look at this value P and Z; which one is larger? As I said the RF C 1; C 1 being the smaller value; that is going to lie at higher frequency.

So, the Z 1 comes at higher frequency, P 1 comes at sorry the C 2; being the smaller one this lies higher frequency, the P 1 lies at higher frequency, Z 1 lies at lower frequency. So, we have been going to get Z 1 first and then P 1 second. And other result; if I look at the overall response as the S is going much lower than Z 1 as well as P 1; this is just 1 therefore, output is equal to V offset; after Z 1, you are going to get a decline with S.

So, 20 db per decade slope and after sorry after Z 1, you are going to get a plus 20 db per decade slope and after you reach P 1, then you get S upon Z 1 and S upon P 1; once you get go much beyond P 1, we have S upon Z 1 and S one upon P 1. As a result both the S cancel out and you are getting P 1 upon Z one. So, that is this particular point is going to be given by P 1 upon Z 1 which is nothing else, but C 1 upon C 2.

So, this is P 1 upon Z 1 which is C 1; upon C 2, this is our gain for the closed loop and at the DC of course, the gain is 1. Therefore, for the V offset since it is the DC signal; we have to look at the gain of 1; for AC signal, the gain is as expected as we look for the frequencies which are provisiontly higher than P 1. So, we know that while choosing the value of this C 2 and RF; we have chosen the RF C 2; such that it is able to pass the signal of interest.

So, this is high pass frequency which is given by the P 1 has to be lower than the signal content of interest and that is how we determine the value of RF over here if you remember. So, while it determines the transfer function; we are anyway seen that this P 1 is determined with the help of RF such that the overall transfer function is able to pass the lowest signal frequency of content.

And our offset is sitting over here; for that the DC gain is just one for the feedback configuration. Using the transfer function also therefore, we can show the same effect signal. AC signal being able to pass all the signals higher than P 1 provided by the cutoff frequency given by RF and C 2; those signals are able to pass and of the signal is just experiencing a gain of 1 in the closed loop operation.

So, the resistive feedback is able to tackle the offset by just introducing the same difference between the output signal as compared to the offset signal. So, the offset in the signal is taken care of; another important thing is; what is the effect of the chopper.

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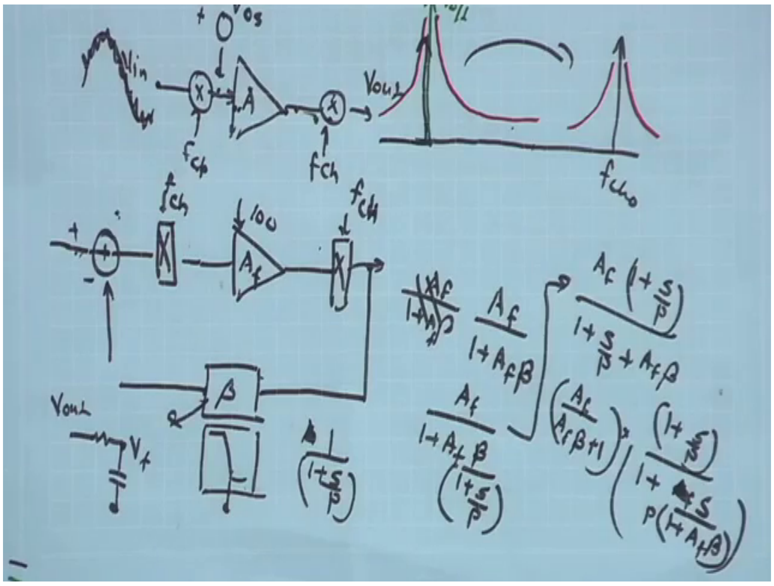

So, we know that if you are putting the chopper in front of the amplifier chopper and the chopper you have f chopped and you have another f chop over here and you have the amplifier over here V in V out.

Now, we have seen that this chopper; what is the role of the chopper? It is supposed to transfer the signal towards higher frequency, which is f chop and the 1 upon f noise of the amplifier remains at lower frequency. Likewise, after the chopping operation the 1 upon f noise of the amplifier goes to higher frequency, signal comes back to lower frequency; that is the operation we have discussed. The noise especially the 1 upon f noise is close to DC; likewise the offset which is over here; you know you have the V offset also added to this; this is also at DC.

So, the chopping happening before the amplifier; the offset is added to the input port of the amplifier; this is just the offset signal because of the mismatch. And as a result you have the final output coming here and then we apply the chopping. So, what is the effect of chopping on this DC signal? Once again we say that the DC signal along with the 1 upon f noise will be shifted to higher frequency.

So, in terms of the chopping operation; since we have anyway included the chopping operation; this offset signal was lying at DC. And then of course, you had the 1 upon f noise; so, both these quantities; the 1 upon f noise and the and the offset signal setting at DC and close to DC, after the anti chopping operation both of them will be getting shifted to the f chop. And the signal is shifted back to the base band or the low frequency content; that was a role of the chopper. The chopper mitigates the effect of the 1 upon f noise; it also mitigated the effect of the offset.

So, even if you have a small offset present; it is separated from the signal level because signal; after the first chopper the signal is at high frequency, the chopping health send the signal to high frequency and offset at this point offset is at low frequency DC. After the second chopping, the signal comes back to low frequency and the DC level along with the 1 upon f noise of the amplifier; goes to high frequency f chop; so, they are remaining isolated.

So, in terms of AC signal it does not really come into picture. So, the chopping also takes care of the offset signal; it is allowing separation of the offset from the low frequency DC signal. Of course, in our case we have not conserved the DC level or the signal; we are anyway trying to reject the low frequency content because you are having noise etcetera and dynamic offset; that we will see just now. But in case of the overall transfer function, it may be important to consider that the offset signal also gets shifted (Refer Time: 29:09) chopping operation.

The other important non ability that we have seen in the example earlier was the dynamic offset and we need to see how to mitigate this issue of the dynamic offset in our amplifier. So, this is the content or a signal and remember when you put the chopper; if you put the chopper before the amplifier, this dynamic offset is presented at very low frequency, but it is present before the chopper. Your actual signal is setting on the top of this dynamic offset, this baseline is fluctuating by large amount and as a result you are having a huge fluctuation over here, you want to reject this and this undesired signal 100 milli volt peak to peak.

And the amplifiers cannot even process these two together because if you want to magnify this 10 micro volt to 1 volt; you can see that this will be magnified much larger. Therefore, we will be clipping the entire waveform; therefore, it has to be suppressed and to do that; we need to take care or we need to add certain things in the amplifier, we need to modify certain schemes in the amplifier so that this offset or the dynamic offset baseline fluctuation can be suppressed; what is the chopping doing? So, chopping is transferring this baseline fluctuation which is a low frequency along with the signal to high frequency f chop. So, after the first chopper; the signal as well as the baseline fluctuation together will be shifted to high frequency. So, this is not isolated; chopping is not able to isolate the base line fluctuation in the signal. Chopping is able to take care of when 1 upon f noise, it is able to take care of the DC offset, but not the baseline offset of the baseline drift in the signal.

And for that we need to make sure that we have an amplifier scheme which is able to reject this. At high level that scheme can be represented as a negative feedback loop for this low frequency signal. So, the target is that we add a negative feedback loop, where this low frequency offset or the low frequency dynamic offset is experiencing a strong negative feedback, but the signal is the input signal is not experiencing that feedback.

So, basically using a say if you are having a feedback factor beta say given by 1 and the A beta is much larger; therefore, the gain can be at least set to 1. So, for this particular dynamic offset the gain can be set to 1; if I have a strong enough feedback beta equal to 1 in the negative loop. But in that need feedback loop; I have set the cutoff frequency so low that the actual signal is not able to pass only the slowly varying dynamic offset the undesired large amplitude dynamic offset is able to pass.

For that; this is a mean amplifier and you have the let me represent the chopper as this rectangle and I have the end chopping over here. So, after this I know my signal is going to come back to the original frequency f chop and f chop. And I establish a feedback; this is not feedback in amplifiers; this is feedback in the entire loop.

So, after the anti chopping; I am putting a feedback network beta and the negative; this beta is having a very sharp, very low cutoff frequency so that it is passing only the slowly varying offset; it is not passing the signal. So, I can represent it suppose it is a first order, I can represent it as 1 upon 1 plus S upon P; it can be just an RC filter.

So, for an RC filter this will be the transfer function; the unity gain at low frequency and at high frequency, it is degrading by; so, just this just can be an RC filter. So, the output of the signal; output is coming here and this is the feedback signal V f; this is the output signal which I can subtract from the input; so, if I do that what is the overall effect?

So, if I look at the transfer function; suppose the A is having much higher poles. So, the poles in A is much higher; I do not worry about the poles of A. This cutoff frequency of the beta is very low, it is able to pass the dynamic offset. So, for this slowly varying dynamic offset, my overall transfer function of this amplifier will be given by A upon 1 plus A beta; this is our A; which is the closed loop gain of the front end amplifier; this is not the open loop gain, this is our original front end amplifier; where we are having the feedback and you are having the closed loop gain may be 100. So, this is what we have said; this is the A f; I can say better call it A f; so, as to avoid confusion with the open loop gain.

So, 1 plus A f beta and what we are saying is the poles of the amplifier are at much higher frequency; I am all though all together ignoring it. I am concerned with the pole of beta; I am passing, I am putting a much low frequency, low pass pole over here so that only the dynamic offset is able to pass; only the slowly varying signal is able to pass; the faster input signal, the desired signal this is not able to pass.

As a result; this transfer function will be given by A f upon 1 plus A f beta 1 plus S upon P; which is the pole of this chosen feedback network. Now, what is the effect of this pole on the overall transfer function; this is I am assuming that A f poles are much higher, I do not even consider that while considering the effect on this low frequency signal. So, what is the effect of this on the order transfer function?

So, I can take it up A f and you have the same function 1 plus S upon P; coming over here and then you have 1 plus S upon P plus; A f beta coming over here. And then if I take 1 plus A beta out; you have A f; upon A f beta plus 1 times; 1 plus S upon P upon 1 plus A f beta; sorry 1 plus S upon; 1 plus A f beta. And if I assume that A f beta is much greater than 1; I can approximate it as, this the first term becomes 1 upon beta.

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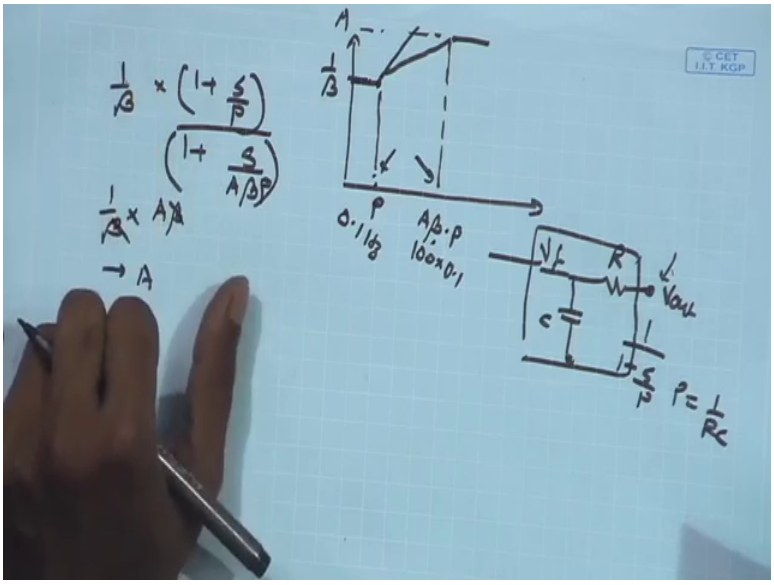

So, in the first term is just reduced to 1 upon beta and the second term you have 1 plus S upon P and you have 1 plus S upon A beta; this is the overall transfer function we are getting for the low frequency signal. Because for the low frequency signal, I have assumed that this is able to pass the low frequency signal comfortably; you have very low pass frequency, low cutoff over here.

Now, what is this behaviour? If I look try to understand this; you have the pole P and sorry I also have the P over here A beta times P. So, in the denominator of course, when you are bringing it down; you have S upon P times 1 plus A beta. So, you have the P; now if I look at the two poles P and A beta time P; A beta is much larger, if I assume beta is 1. Because, if I am assuming RC filter for the beta; the transfer function is 1 upon; 1 plus S upon P. If you just have the beta output signal coming over here and this is the feedback signal V f.

The transfer function is 1 plus S upon P; where P is equal to 1 upon RC; this is what we have for the simple RC filter. This is the output signal being sensed by the beta network and this is the feedback signal provided. So, I am replacing the beta by a simple RC network, so the beta for the low frequency signal is simply replaced by the RC network. And in the case; the pass band gain is anyway one unity; below the pole P the gain is unity.

Now, if I look at these two another function; what is the overall behaviour? This is A beta times P which is lying at much higher frequency. When you have omega much lower than P, the overall gain for the low frequency signal; from this input to the output for the low frequency dynamic offset, the gain is going to be 1 upon beta; if S is much smaller than P.

So, very low frequency the gain is just 1 upon beta and then if I am going towards frequencies; say much greater than P, then of course, you have the S upon P term coming over here and as a result; you are having the gain increasing. So, the gain starts increasing with S upon P; till what point it increases?

So, you have the frequency A beta times P; after the frequency A beta times P is reached; the overall S factor will be cancelling out and as a result, you will be getting 1 upon beta times A beta; that means, just A. That is after the frequency; A beta times P, the gain of the loop reaches A; which is the desired gain for your signal; that means, if you are setting the pole of this low pass filter at P; till the overall transfer function of this loop is going to become A; only after A beta times P.

So, means if the signal content is higher than A beta times P; the desired signal content is higher than A beta times P, it will be able to pass through this filter whereas the signal content lower than A beta times P, it will be automated as well. So, what I want is that the P should be set such that it is rejecting the low frequency dynamic offset, but at the same time A beta times P should be such that; my pass band signal, the desired signal is able to pass that is the criteria in setting these two points.

For example in our application; if I want to set P; say point 1 hertz and the A beta quantity; what is the beta? if beta is 1 for low frequency. So, beta is 1; A is 100; so,100 times 0.1; so, it is 10 hertz; so if I keep this as point 1 hertz; the low pass cutoff frequency of the filter in the feedback 0.1 hertz; this will be 10 hertz, this means the signal content below 10 hertz will also be suppressed.

But if we are using; if you are looking at say the signal content say you want to pass signals in the range of 1 hertz or you know that the EC; the neural potential signals; they are looking at it, can have range up to 0.5 hertz. So, we must make sure that this A beta times P is not very high. So, in that case the; A beta will be very much limited just 5 therefore, the loop; the A gain that you are having for the main amplifier that also gets limited.

So, we have to make sure that this A beta times P factor is sufficiently low so that my desired signal sitting at 0.5 hertz or higher, it is able to pass while the undesired signal sitting at 0.1 hertz or lower is able to be blocked; that becomes challenging and for that we need to make sure that the transfer function in the feedback path is such that it is able to suppress or it will able to provide a steeper roll off.

So, other than having a single pole response; I can have a steeper response over here two pole response and in that case this curve can rise steeper. So, other than putting just a passive RC filter over here; I would like to put some active filter or higher order filter so that the stiffness of this transfer function can be much stronger; that is what we need to look into. And apart from that another thing that we need to make sure is that the whatever we are adding over here is not contributing any noise to the main input. Because the moment we add any active component over here or any transistor level circuit over here; if this starts contributing noise to the input; it can create lot of problem.

Therefore, I would like to make sure that this particular component if you are using any active component over here, it does not add noise to the input point otherwise it is going to interfere or it going to degrade my SNR. So, the design of this loop becomes important and we have to consider the overall feedback system, where we are trying to pass our desired signal and trying to block our undesired signal with the help of a desired beta factor.

So, we need to look into this and try to see that at first of all block level; how do we choose the parameter for this beta network and second at transistor level how to implement this connectivity and ensure that while achieving low noise, we are able to reject the undesired signal. And for that one option that we would; obviously, see here is that you can make the beta greater than 1.

So, you are using a feedback system; where you can make beta greater than 1, then once again we can ensure that the desired signal will be passed sufficiently whereas, the undesired signal will be suppressed strongly. So, we need to see that how to make the beta stronger maybe greater than one while making sure that it is not contributing to noise.

So, if the beta here is greater than 1; that means, from here to here you are trying to put gain and the moment you put some active circuit to put a again; that means, again noise contribution is going to come. That is required to keep beta higher and then suppress the undesired signal, but at the same time it should not corrupt the signal with additional noise in the circuitry. So, this loop becomes very critical and we need to see how to come up with appropriate design catering to the beta requirement, the noise criteria and cancellation of this wide swing dynamic signal.

So, let us stop here and look at this problem of dynamic offset cancellation in more detail in our next module.