VLSI Data Conversion Circuits
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Lecture - 22
Stability of Delta Sigma Modulators

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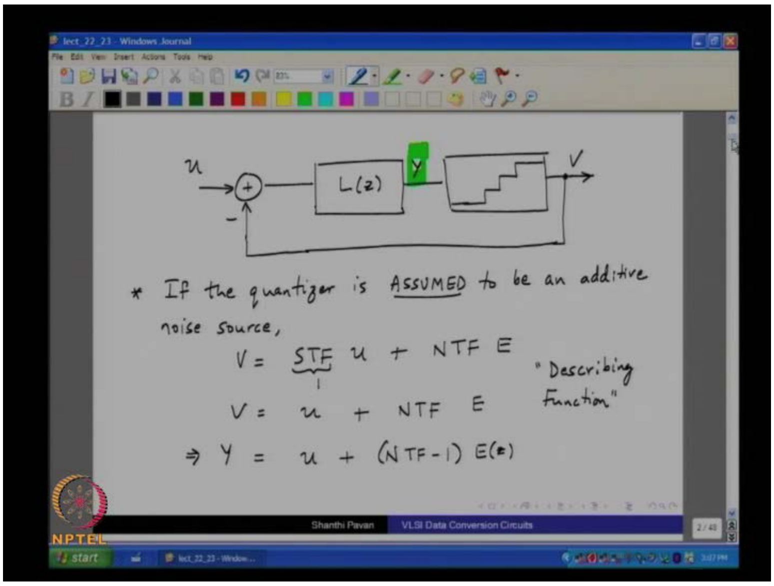

This is VLSI data conversion circuits lecture 22. In the last class we were wondering what would happen to a delta sigma modulator; where we have a low filter, a specific example being something like this going into a quantizer which flows the negative feedback loop around this; this input signal which is denoted by u, the output of the quantizer which is denoted by V. And, the output of the loop filter which is denoted by 1. Now, if we assume that this quantizer here behaves like an additive noise source; then the Z transform of this sequence Y was calculated to be what?

Student: ((Refer Time: 01:55)).

So, we said that V was u plus or rather V was nothing but STF times u plus NTF.

Student: Times.

Times E; where E is the quantization noise. And, this is approximately 1; which means that V is u plus NTF times E; I am omitting the ((Refer Time: 02:30)) all over the place.

And, therefore the signal at the input the quantizer Y will be given by u plus NTF minus 1 into E right, all right. In the last class we were wondering of course this is all nice if the quantizer is indeed an additive noise source. However, a practical quantizer apart from being horribly non-linear also will have saturation; the levels I mean if you go on increasing the analogue input the output is not going to keep increasing; in other words the staircase has got some limits. And, we were trying to see what would happen to the behaviour of the delta sigma loop if the quantizer saturates right?

And, I mean given that this is a non-linear system with feedback; the analysis if done rigorously would be you know difficult to do given its non-linear also. So, we resort to some techniques where we would try and approximate the non-linear characteristic or a non-linear system by a so called the best cut linear system. Then, we assume that we have learnt spent a lot of time learning linear stuff. So, you might as well apply all that theory to this so called linear system; which is you know by definition a close whatever relative of the corresponding non-linear network.

So, this kind of analysis which has its origins in the earlier fifties is what is called describing function analysis; that the basic idea is to replace a non-linear system with an equivalent linear system; of course when must bear in mind that when whenever one tries to do things like this; there will always be cases where it does not work out at all right. So, this is not you know a bulletproof way of analysing this. But it gives us many insides to system operation right and allows us to make at least the right direction of design choices. And, helps us gain intuition about how this whole loop works? To get exact results of course one would resort to computer simulations which in this day and age is pretty straight forward and simple to do.

So, we will not get into the ((Refer Time: 05:22)) of you know finding the describing function and analytically and finding using it to find you know stability criteria; and all this stuff. What we are going to do instead is to give I mean to give ourselves an idea of this whole process. And, most importantly develop intuition about a why the modulator becomes unstable right? And, b changing these parameters in some direction. For example, one might decide that you increase a number of levels in the quantizer right; one would naturally worried about or rather curious about what this does to the stability of the loop right; these are normal tradeoffs. For example, you increase the number of levels in the quantizer you choose a higher order things like that which are you know design parameters or design choices. And, we would like to understand how choosing one of these things influences the stability of the loop and what the tradeoffs are?

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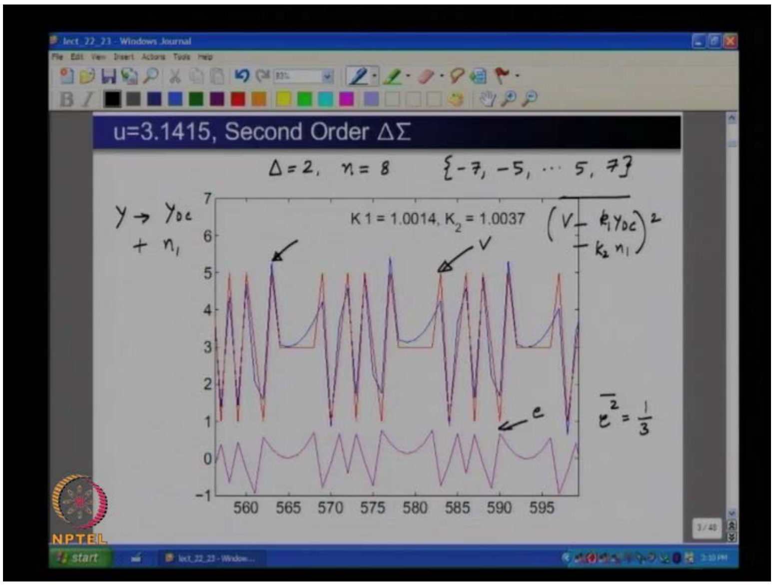

To that end the last time around we saw we took a second order delta sigma modulator with 7 levels; where was a 7 levels are the levels were minus 7 through.

Student: ((Refer Time; 06:46)).

8 level quantizer, right. So, delta was 2 and the number of levels n was 8. So, they go all the way from minus 7 minus 5 all the way up to 5 and 7; when the input to the modulator is made to be well within the quantizer range. You see that the red curve here or the red sequence here denote the modulate output that is V and the blue one here is.

Student: Y.

It is not Y please recall from the discussion in we had in the last class that the Y can be decomposed into the YDC.

Student: Plus.

Plus.

Student: ((Refer Time: 07:44)).

n 1 right and given that YDC plus n 1 is incident on this non-linear device; we tried to approximate this to a linear system by finding.

Student: K 1, K 2.

K 1 and K 2 such that you minimise the error V minus K 1 times YDC minus.

Student: K 2 times n 1.

K 2 times n 1 you minimise the average squared error; that is the best you can do in other words you try to choose K 1 and K 2 intelligently such that the error between a linear approximation and this non-linear devices has smallest possible. Obviously, the fit will not be when you try and attempt to do this; you will find that the error is not 0 the error would only be 0 if.

Student: Quantization ((Refer Time: 08:43)).

If the box was a linear system, correct. So, this happens to be the error waveform. And, if the input plus the quantization noise that is YDC plus n 1 lies well within the quantizer range; it should come as no surprise that the mean square value of the error.

Student: Delta square by.

Has been delta square by 12 going you know through I mean going by the original arguments that we had about the input was busy. And, then the quantization error is uniform and in which case its mean square value will be delta square by 12. So, it indeed turns out that this mean square error happens to be about one third which is delta square by 12. So, this is not surprising.

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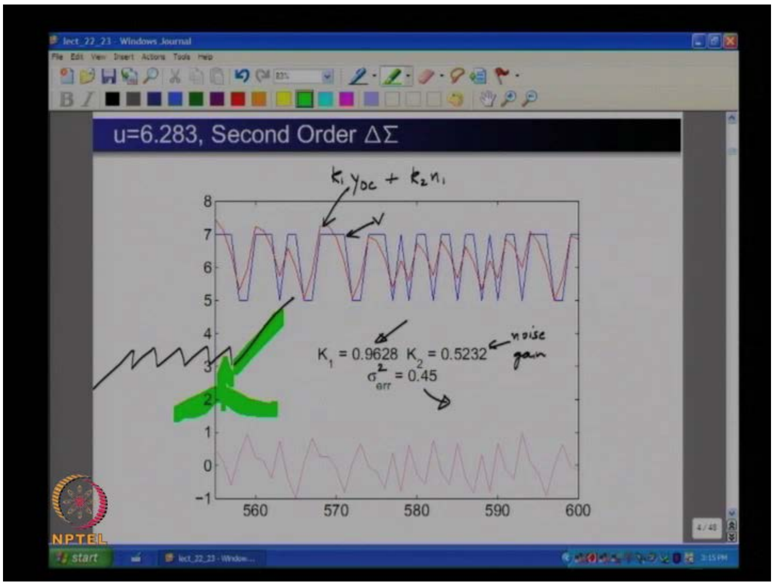

Then, what do I will increase the input amplitude or rather increase the DC value; such that for the same modulator I have doubled the input; please recall that the maximum level is plus 7 right. So, the input is 6.28 in this case and on top of it there is some shape quantization noise; you know riding over this d c input right which now means that the quantizer will.

Student: Saturate.

Will saturate and seems like that is happening quite often as we can see in this picture. So, if the quantizer saturates we see couple of things happening this is V, this is Y I am sorry this is not Y this is K 1 times YDC plus.

Student: K 2 times.

K 2 times.

Student: N 1.

N 1. And, since we are now saturating the quantizer right it makes sense that we are not able to fit this you know quite as nicely as we were able to fit it during the; I mean in that region where the staircase had a gain of one for both the noise and the d c component. And, that does come out in the maths; the gain for the signal is close to 1 right; this is again not too surprising. Because as far as the input signal is concerned and it is still within the.

Student: Linear range.

Linear range of the quantizer right. However, the gain for the noise is now significantly lower what was close to 1 is now dropped to 0.5. So, this is the noise gain. And, we see also see that the mean square value of the error has increased from.

Student: 0.5 to ((Refer Time: 11:51)).

Delta square by 12 which was one third the something which is about 30 percent high this also makes sense. Because please recall that the error of the quantizer is only bounded; when the input is within the linear range of the quantizer, correct. So, if you plot the quantizer error transfer curve it is some saw tooth kind of waveform within the quantizer range; beyond the quantizer range it will go to eventually go to infinity you understand. So, the quantizer quantization error transfer curve will probably look like this. And, right now the input is sitting somewhere here on top of it there is quantization noise riding. So, you can see that when the quantisation noise really starts to become large right; the shape quantization noise you will easily excite some part of the characteristic where the error is large. So, it makes intuitive sense that the mean square value has gone up from delta square by 12. But the key point is to notice that the noise gain has.

Student: Dropped.

Dropped and dropped quit dramatically correct. And, intuitively this makes sense because I mean the noise is now saturating the quantizer. And, the when the quantizer is saturated there is really no connection between there is no resemblance between the output waveform and.

Student: Input waveform.

The input waveform. So, it is almost that noise is not coming out at all which on average terms means that the gain has come down; does make sense all right?

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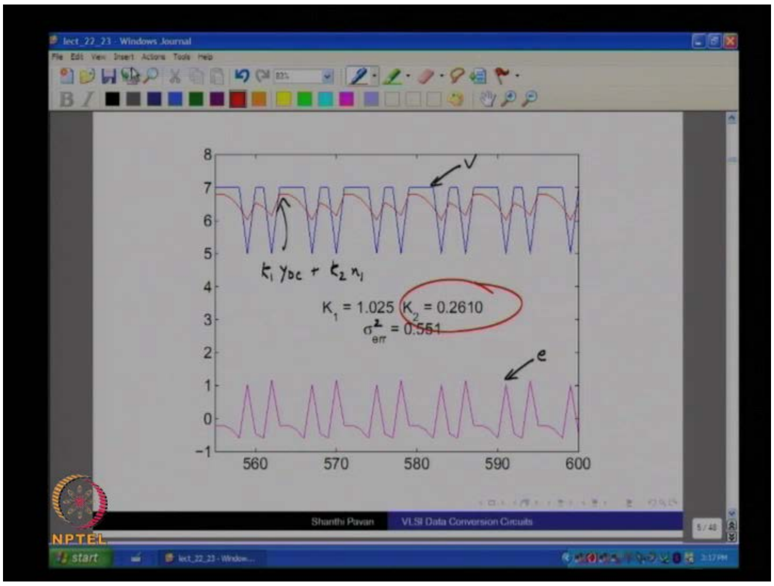

Now, let me up the ante a little bit an increase the DC input to from 6.3 to about 6.5. And, this must only make things even worst for the noise correct. And, again as you can see this is V this is K 1 into YDC plus K 2 into n 1 and this is the error. And, you can see that the mean square value of the error has gone up a little bit. But the most significant thing that you must notice is that the gain for the noise has gone down even further right. In other words a small change in the DC value close to the linear range of the quantizer is enough to push the gain for the quantisation noise down dramatically; what was one can fall down in this case as we have seen has gone down to a 0.26 or so. So, you understand. So, the question now is what happens.

Student: When did ((Refer Time: 15:09)).

Well, I mean this I would suspect some place simply numerical and I mean it is not a significant effect I think it is still close to one right.

Student: ((Refer Time: 15:21)).

Ah pardon.

Student: We keep on increasing YDC I mean when this K 1 will also come down right.

Eventually yeah. So, I will suspect what is happening is that this input is close to see 6 point something right. And, the output now stays mostly at 7. So, it appears as a.

Student: Some increase.

Some slight increase that is all I do not think this 1.025 is the significant.

Student: Sir, this gain K 2 will come down even when we decrease YDC very low right.

Of course so.

Student: This situation is on the both side.

That that is good, that is a good point. So, what he is pointing out is that even when the quantizer saturates towards the.

Student: Negative.

Negative side this same thing must happen correct great.

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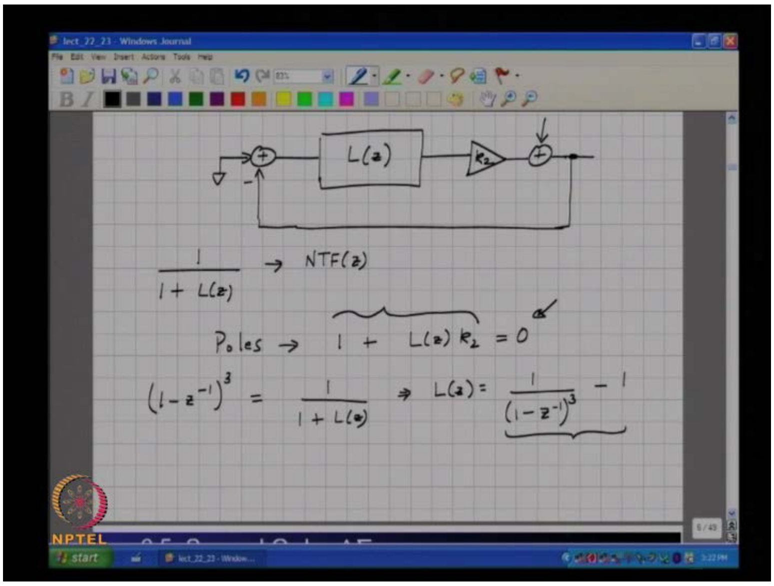

Now, let us see what happens now when you have a high order loop filter; please note that the motivation for this discussion was the following; we found that 1 minus z inverse was giving us good in-band SQNR. I mean we got gradients at we put 1 minus z inverse whole square; it was getting better. Then, we said hey why not 1 minus z to the minus 3 or I mean 1 minus z inverse the whole cube or 4 or 5 or 6. So, in other words we would like to make this L (z) have as high again at DC as possible. And, roll off you know at as

1 by omega cube for small frequencies; then you will expect to get a noise transfer function which is 1 minus z inverse the whole cube right.

So, in general given an NTF we can always go and find L (z) using 1 by 1 plus L (z) gives the NTF all right. And, now what is happening as we discussed in the last class this system can be broken up into 2 as far as analysis of stability is concerned right. If you do not like to think about it as 2 systems you can always think of the input as being given are background an analogue right; as the input as being the quiescent value. And, replace everything in the loop by as its incremental equivalent correct. So, then we have the loop filter; so the quiescent value becomes 0. So, you can think of this as the incremental picture of the entire loop; given that the quantizer is non-linear. The only thing we need to worry about is instead of having a quantizer we have a gain K 2 plus some fitting error E and this feeds back. So, the true transfer function or the poles of this loop are given by the roots of what equation?

Student: ((Refer Time: 18:40)).

1 plus.

Student: L (z) into K 2.

L of z times k 2 equal to 0. So, clearly K 2 influences the locations of the poles; and can therefore influence the stability of the loop. Because stability is all I mean you want to make sure that the closed loop poles stay within the unit circle; if you want a stable system does it make sense all right? So, I did an experiment I chose the NTF to be 1 minus z inverse the whole cube from which I formed L (z); which means what is the L (z)? 1 by 1 minus z inverse the whole cube.

Student: Minus 1.

Minus.

Student: 1.

1 all right. And, then given that I know L (z); I can go and find the roots as K 2 is changing from.

Student: ((Refer Time: 20:15)).

From 1.

Student: To 0.

To 0 correct; I mean K 2 equal to 1 corresponds to what?

Student: ((Refer Time: 20:24)).

Corresponds to the modulator being.

Student: It is 1 by 2.

Being in that in uniform staircase region right. And, as we as the input signal gets closer and closer to the saturation limit K 2 will fall. So, we plot the locus of the poles of the system which are the roots of 1 plus K 2 times.

Student: L (z).

L (z) as K 2 varies from.

Student: 1 to 0.

1 to.

Student: 0.

0. And, I have done that experiment for you.

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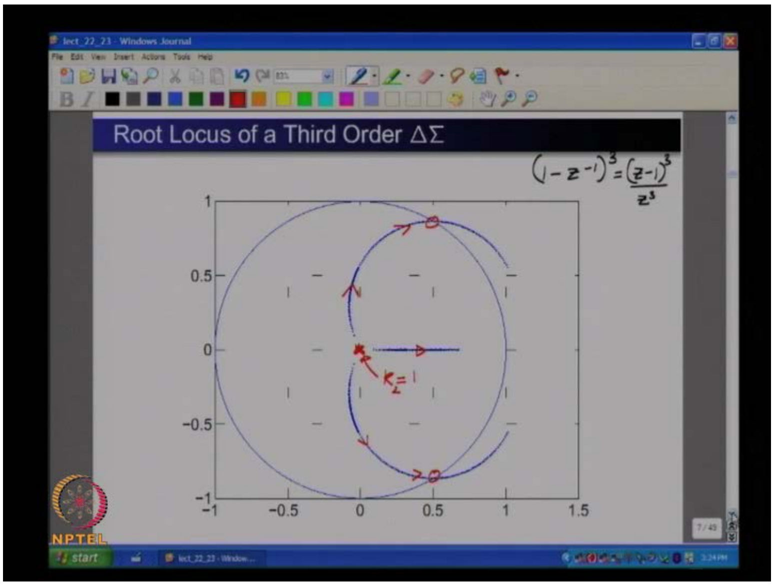

I hope you are able to see this all right. So, the shown here is the unit circle. So, K equal to 1 where are the poles?

Student: ((Refer Time: 21:22)).

Where do you think the poles are?

Student: ((Refer Time: 21:28)).

I mean when K equal to 0 the closed loop system has transfer function of 1 minus z inverse the whole cube right; which is nothing but z minus 1 the whole cube divided by.

Student: z cube.

z cube. So, all the 3 poles will be at the origin. So, this corresponds to K equal to.

Student: 1.

1. And, as K 2 keeps increasing I mean as K 2 keeps falling what happens is that the poles you must realise that 2 of them will be complex conjugate; which means the poles must. I mean if one if on top there is a pole there is corresponding pole in the lower half. And, as you can see as K keeps falling at some critical value of K.

Student: They cross the unit circle.

They cross the unit circle therefore.

Student: Unstable system.

Causing the system to become unstable. So, one pole remains inside but these complex conjugate poles keep moving towards the unit circle as K falls down. And, for some critical value of K they cross the unit circle beyond that they actually get out of the unit circle; which means the impulse response corresponding to those pole locations is a sequence which grows exponentially is this clear? So, let us see what that value of K is?

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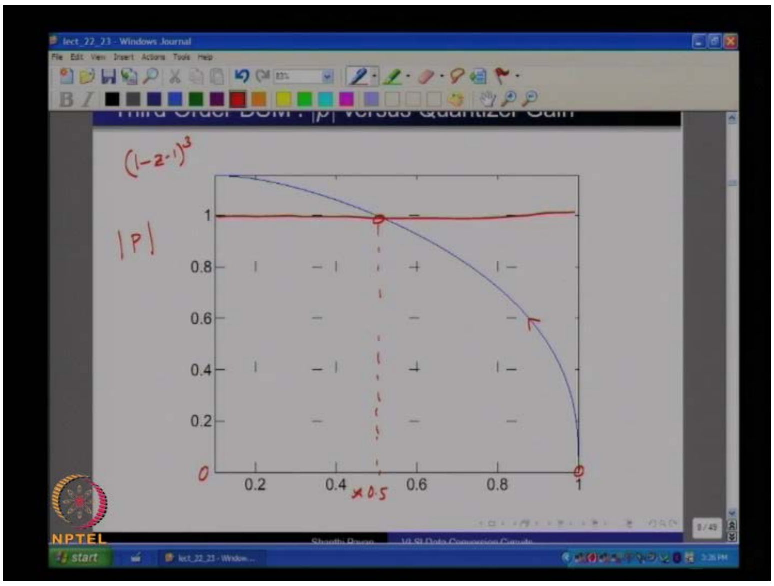

So, what I did was plot the magnitude. So, this is the magnitude of the largest pole as the function of K; when K equal to 1 what should the magnitude of the pole b?

Student: 0, 0, 0.

0 right that makes sense. So, as K keeps falling we can see that the magnitude of the poles keeps increasing. And, what is the critical value of K at which the system becomes unstable?

Student: ((Refer Time: 24:02)).

When the magnitude of the pole becomes equal to 1 and that happens around 0.5 or so is this clear. So, what we see is that once the quantizer gain falls below 0.5; if we attempt to realise a noise transfer function of the form 1 minus z inverse the whole cube; you will find that the modulator becomes unstable. In other words the input of the quantizer will simply blow up. Because the impulse response now has got components which do not die down at all with time; which means that the input to the quantizer will blow off. I mean you should not be tempted to conclude that the system will be stable by looking at the output of the quantizer; you understand. The output of the quantizer always be bounded because it is saturating from at minus 7 and.

Student: Plus 7.

Plus 7; you have to look at the input to the quantizer. And, make sure that none of these state variables inside the system actually.

Student: Blow up.

Blow up to infinity is this clear? So, this explains the signal dependent stability of the modulator.

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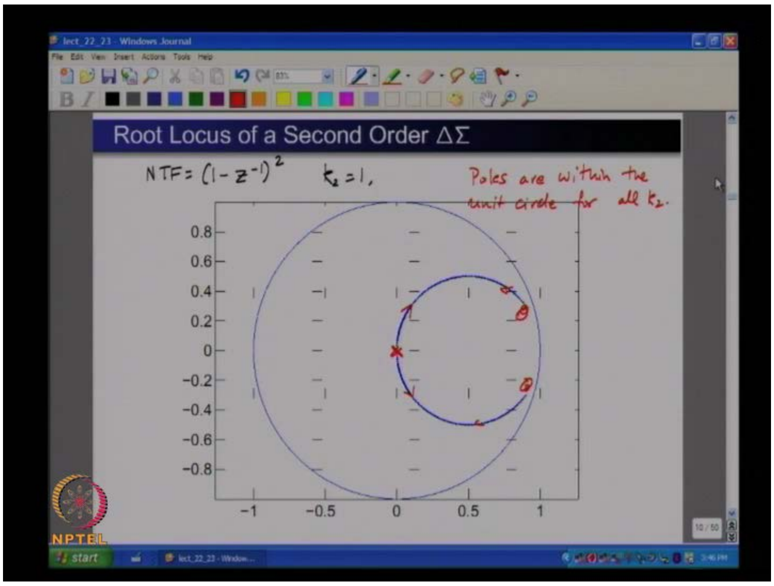

So, this is a third order root locus example; I also did that for a second order delta sigma loop; again what corresponds to the NTF is 1 minus z inverse the whole square. So, for K 2 equal to 1 where are the poles located?

Student: ((Refer Time: 26:12)).

At K 2 equal to 1 the poles are located here. And, as K 2 keeps falling we see that the poles do indeed move right but you can always.

Student: ((Refer Time: 26:26)).

See that they are within the.

Student: Unit circle.

Unit circle all right; this is somewhat analogous to you know that whenever second order system regardless of the value of the gain in continuous time systems; you see that the poles were always lie in the.

Student; Left half s plane.

Left half s plane right. And, I mean they will never get into the right half path. So, this is a somewhat similar result; regardless of what K 2 you have the poles will move but they are always sitting inside the unit circle. So, what happens the question is what happens to the input of the quantizer when the input exceeds a certain level? And, what will happen is that the input to the quantizer will become very large. And, I mean the entire noise shaping property of the loop is lost.

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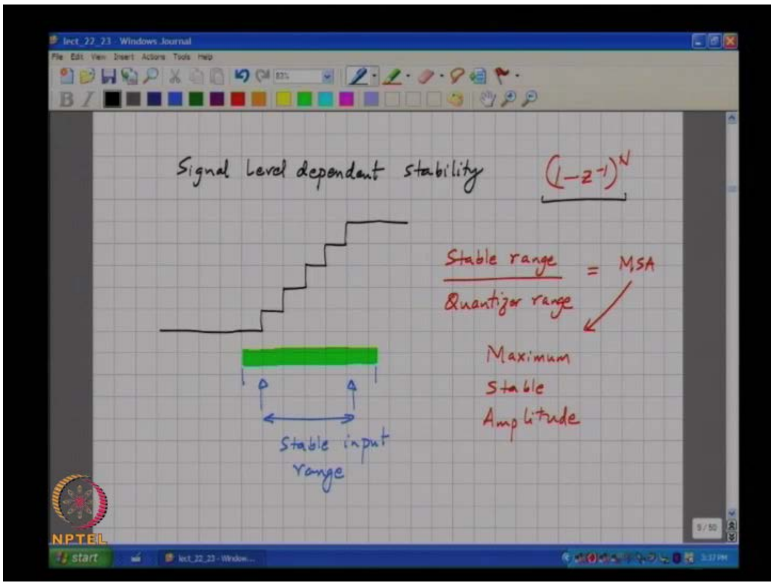

So, in other words signal dependent stability is something that one has to expect with this kind of system. So, in other words this nice property of the in band noise being very small can only be achieved when the quantizer does not saturate. In other words the input to the quantizer always lies within this range. But please note that the input to the quantizer and the input to be digitized are 2 different things; 1 is Y the other is.

Student: U.

U. So, if Y has to be restricted to the range of the quantizer it follows that U must be.

Student: Bounded term bounded term bounded term must be lower.

Pardon.

Student: YDC plus n 1 should be lower than the it should lie in the range of the.

Quantizer. So, what calculation can you make about U?

Student: Less than the maximum is less than less than the.

So, clearly if this is the range of the quantizer right the input cannot be.

Student: ((Refer Time: 29:55)).

Cannot occupy the full range of the quantizer it must be smaller by some amount. Because you must leave some range for the.

Student: ((Refer Time: 30:06)).

Shape quantization noise to wiggle or ride over the input. So, this is the let us say pictorially this is the stable input range. So, the ratio of the stable range of inputs to the quantizer range itself is often called the MSA or the maximum stable amplitude. Now, given that we have this intuition. Let us try and figure out what would happen if we went on making the noise transfer function more and more aggressive; in the sense that we started off with 1 minus z inverse then 1 minus z inverse the whole square. Now, we go to 1 minus z inverse the whole cube. And, in this process what do you think is what do you think will happen to the maximum stable amplitude?

Student: It will decrease.

It will.

Student: Decrease.

Decrease and why does not make sense?

Student: Gradients of noise varies.

So, as the order of the noise shape in goes on increasing we see that the gain at out of band frequencies; that is the gain at omega equal to pi is going on increasing by a factor of 2 every time; which means that the variance of the noise riding over the input signal is going on increasing. If the variance of the noise increases then what will happen? The probability of saturating the quantizer is higher; which means that even if the input is small right. Because of this lot of noise shaping going on; we see that the shaped quantization noise is going to saturate the quantizer there by causing the loop to become unstable. So, as you go on increasing the order of the noise transfer function; if we did not do anything if you made the noise transfer function 1 minus z inverse to the power n right. We will see that the maximum stable amplitude will be a very small fraction of the quantizer input range. Because you have to accommodate now the increased variance of the.

Student: Noise.

Shape quantization noise correct. And, the shape quantization noise and all these assumptions makes sense when you starting from within the middle of the quantizer and keep going up. Because as long as you do not hit the saturation limits; you know the quantizer can be pretty much thought of as a additive noise source. It is only once you start saturating the quantizer that the gain for the noise becomes smaller than 1. And, if the loop filter is of high order which is what it would be if you want to realise 1 minus z inverse to the n. Then, the quantizer effective gain for noise become smaller causing the noise variance to increase, causing the quantizer to saturate even more. And, this is like you know regenerative process you know will cause the input of the quantizer to suddenly blow up in magnitude; does it make sense? So, this is why it is not one cannot go on making N.

Student: Larger and larger.

Larger and larger and large you understand; couple of points that I would like to make here does somebody have a question. So, couple of points I would like to make here what do you I mean one thing is we are going to make this system right; we understand that there is a maximum stable range or maximum stable amplitude. Let us say my input is beyond the maximum stable amplitude. So, clearly the system becomes unstable the input to the quantizer just blows up; after this let us say I bring my amplitude down to within the stable range or let me just say to matter simple. Let me say I just simply make the input 0. So, the input I started from 0; I went on increasing it beyond a certain point the modulator becomes unstable. And, you know the state variables inside my loop filter become unbounded become very large. Then, I realised that something is wrong and suddenly say enough is enough and I ground the input.

So, that the input is now technically within the stable range of the modulator; what do you think will happen, do you think the modulator will continue to oscillate or do you think it will comeback given the inputs are?

Student: ((Refer Time: 35:59)).

Pardon.

Student: Keeping the situation let us illustrate.

Ok.

The input was 0 first, right. So, this is well within the linear range of the quantizer. So, I go on increasing the input eventually the amplitude will become large enough; that it exceeds the maximum stable amplitude. Then, the loop becomes unstable and therefore the state variables inside the loop which basically are the voltage levels or mean or the values inside L (z) start to blow up. Then, I immediately sense something is wrong and make the input 0; which is clearly within the well within the quantizer range. Now, the question is what do you think happens?

Student: ((Refer Time: 36:51)).

Why?

Student: Less of multi feedback.

So, it so turns out that for a second order modulator things do indeed come back and the intuition goes like this. So, when the modulator is unstable the internal state variables are very high. So, the quantizer is saturating like anything correct; which means that the effective gain of the quantizer for as quantization noise is.

Student: almost there is no there is not ((Refer Time: 37:46)).

It is very very small. So, in other words the poles are somewhere around here you understand; this is the root locus for a second order modulator as the gain starts from one and keeps falling down to.

Student: 0.

Not 0 in this case I think it is 0.1 but never mind right. So, the poles are still within the unit circle. Now, think of the situation is the following we have a system whose poles are within the unit circle. And, you start off the state variables at some very large values and the input is 0. So, if you have a stable system with initial conditions being very large right but the system is stable and the input is 0; what will eventually happen to the states?

Student: Come down come down.

They will.

Student: Die out slide down die out.

They will eventually die out, correct. So, for a second order modulator right if the input was such that it push the modulator for a little time outside its; I mean the region where it is stable. And, then the input was brought back or made 0 for example then what would happen?

Student: It should die out and.

We see that we are somewhere here you can think of it as staring off here. And, then these states will tend to decrease in magnitude because the poles are within the unit circle correct. And, as the states decrease eventually you will come to a situation where the.

Student: ((Refer Time: 39:41)).

You do you stop or you reduce the degree to which you saturate the quantizer; which means that the gain goes on.

Student: Increasing.

Increasing. So, you come back along this curve and we have still all right; unfortunately this is not true when you have.

Student: Higher order higher order modulator.

A higher order modulator because the intuition of course this is the whole process is extremely non linear and very complicated right. So, all that we can do is get some intuition about you know what why things happen the way they do; all right. So, I will in one of your home works you will do this. And, convince yourselves that this is indeed true; you know third order modulator for example, when the modulators become unstable the variance of the quantization noise or rather the input to the quantizer becomes so large that you are you know deep inside the.

Student: Unstable region.

In the unstable region that is way outside the unit circle. And, making the input 0 does not really help because you are still outside the unit circle; and these state variables have you know are still growing exponentially. So, you will find that modulators with order 3. And, higher correct will become unstable beyond there you know within quotes linear range or stable range. And, more importantly it is not straight forward to make them stable again by bringing the input back to within the stable range; you have to do something more all right. And, once common thing that is done in products is to simply zap the state variables I mean the problem is that the now earlier the problem was that the input was too high. And, was causing everything to oscillate and the causing the state variables to become very large; it is very easily detected in practice. When the modulator is become unstable right one thing to do is just check the input to the quantizer. If it become very large then you that the modulator is unstable. And, you can you know bring it back into the stable region by a making sure that the input does not exceed this the maximum stable amplitude. And, to you bring state variables back to you know same levels and the easiest thing to do is to simply make them all 0.

So, you can detect when the modulator has gone unstable right and reset all the states; and you start of all over again you understand. So, amplitude induced oscillations which do not go away once the input amplitude is gone down is a characteristic of non linear system; it is not just observed in delta sigma modulator loops. But also in continuous time systems; where it is a property of non linear systems that is all. So, you can have the you can have these systems lock into non linear oscillations they have been triggered by some input. And, then even after the input goes away the oscillations continue you understand. So, the summary of the whole thing is that a delta sigma loop is only stable for.

Student: ((Refer Time: 43:34)).

Input signal range which is a part of the quantizer range; it cannot be the entire quantizer range. And, the reason for that is that the true input to the quantizer is the input to the modulator plus.

Student: Shape quantization.

Shape quantization noise and the loop is becoming unstable because the quantizer is saturating, correct. So, anything that you do which will increase the variance of the shaped quantization noise is bound to result in.

Student: ((Refer Time: 44:15)).

A reduced maximum stable amplitude correct. Because the input of the quantizer has to accommodate the shape noise plus the input it makes sense; that I mean increasing the order of the loop 1 minus z inverse to the N for example, will dramatically increase the variance of the shaped quantization noise; which will then therefore make the maximum stable amplitude a small; is this clear. So, we are now in a situation where we have the following; we really like 1 minus z inverse to the N why do we really like it?

Student: In band noise in-band noise in band noise.

In band noise I mean is reduced by a large factor correct. And, we are getting if we have 1 minus z inverse to the N; then you get N plus half bits every time you double the.

Student: OSR.

OSR. So, seems like a really really attractive thing; on the other hand the maximum stable amplitude is.

Student: Very small.

Is very very small or keeps on reducing. And, in practice becomes very very small when you have.

Student: N should be large.

When N becomes large. So, the question now is what do we do to make we want to have the best of both worlds; you certainly want to have 1 minus z inverse to the N. However, you want the maximum stable amplitude to be.

Student: High.

High also correct. So, the question is what do we do about this you understand?

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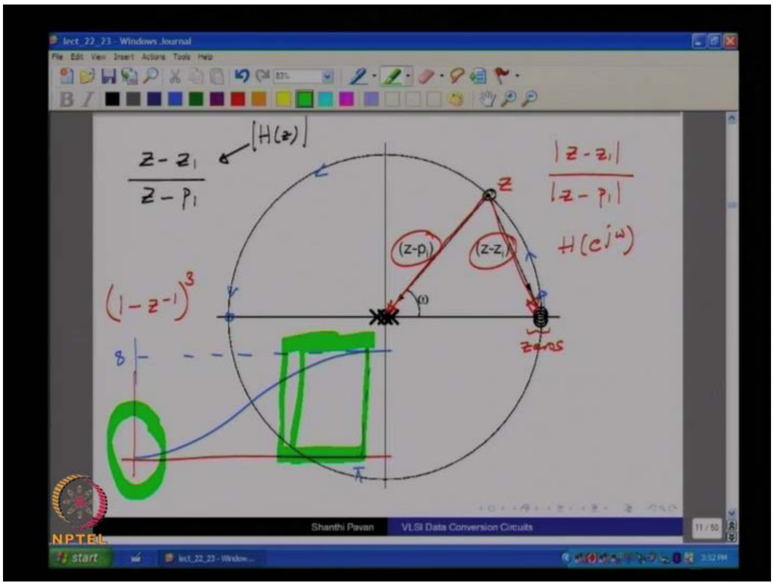

So, let me quickly refresh your memory about finding the magnitude of a transfer function. Let us see you have a transfer function Z minus P 1 divided by sorry Z minus Z 1 divided by Z minus P 1; how would you graphically determine the magnitude response evaluated at H (z); I am sorry what I meant to say was how will you determine the magnitude response of H evaluated at z.

Student: Find the ((Refer Time: 47:05)).

Yeah. So, of course you can plug in Z into the formula and then find the ratio complex numbers and this. But what I wanted to bring to your attention is a fact that this is z which is the point at which you need to evaluate the magnitude of this transfer function; what you can think of as you can think of this process as finding the distance from z to.

Student: ((Refer Time: 47:33)).

To all the poles right and you will get the magnitudes of those vectors. And, you find the distance from Z to all the zeroes and you find the magnitudes of those vectors. And, find the ratios of the magnitudes of the vectors which go to zeroes to the magnitude of the vectors that go to the poles. And, that gives you the magnitude response correct. And, in our situation we are pretty much interested in finding the magnitude of H (z) or the NTF; as we travel along the unit circle correct in other words we are interested in evaluating H of E to the.

Student: J omega.

J omega, all right. So, what I wanted to point out is that when we have 1 minus z inverse the whole cube what is happening? There are 3 poles at.

Student: At origin 3 in origin.

At the origin correct the poles and then there are.

Student: ((Refer Time: 48:49)).

3 0 at.

Student: D c also applicable.

D C or z equal to 1 right. Now, when we plot the magnitude of the noise transfer function; all that we are doing is going along the circle. And, for each point at each point we are drawing these vectors from that point to the poles that point to the zeroes and whatever. And, plotting the finding the ratios; please note that wherever you are on the unit circle the distance from that point to the poles always remains; for this pole 0 constant relation the distance to the poles always remains the same. So, that remains 1; at D C this distance goes as.

Student: 0.

A 0 at D C. And, then starts to go as omega q right and at omega equal to pi what do you get?

Student: 2.

Each vector becomes 2. So, 2 the whole cube becomes.

Student: 8.

8; in other words the NTF kind of does something like this. So, let me all right this is 8. So, we need to what we do not like what is responsible for the modulator going into oscillation?

Student: ((Refer Time: 50:20)).

Pardon.

Student: Finding the finding the ((Refer Time: 50:24)).

Fine this is the problematic part. Because as we saw the last time around most of the contribution to the shape quantization noise is coming from.

Student: High frequency.

High frequencies; that is frequencies in their in the neighbourhood of omega equal to pi right. So, this part of the NTF is something we like that is giving us that omega to the 3; what we do not like is something is the part of the characteristic at omega equal to pi. So, in the next class we see what we do to fix this problem. And, make get 1 minus z inverse the whole cube as well as.

Student: ((Refer Time: 51:08)).

Pardon.

Student: Because finding a problem within the omega is in the pi region.

Correct.

Student: So, like we have to decrease this mean in that region.

Correct. So, what does this do eventually the whole modulator; what is that improving?

Student: ((Refer Time: 51:25)).

It is going to increase the MSA. So, you can get the good noise shaping without losing too much on the MSA right. So, we will see that in the next class.