Communication Engineering

Prof. Surendra Prasad
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture - 40
Delta Modulation

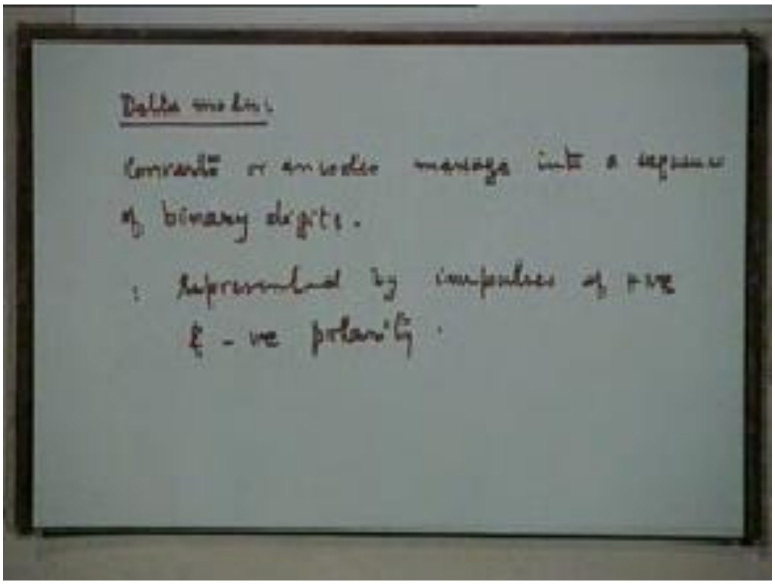
So, yesterday we looked at the importance of representing analog information into digital form and the communicating this information into digital form. Because, we found we argued that if we do things that way we are able to perform much better in the presence of noise, than if you want to just transmit the information in the analog form. Of course, the key to this better performance is the use of repeaters, regular regenerative repeaters, which at intermediate points will clean up the signal and retransmit, retransmit the cleaned up signal. And that is the reason this benefit of improved performance at loose if you transmit digital information, rather if you transmit the information in the analog form.

So, the issue that arises how do you convert your analog information if you want to transmit into digital form and towards the end of our course? We are basically going to discuss two techniques which we will convert analog information into a binary digital representation, which is something already known. The context of A to D converters, but we will look at it from the communication theory point of view. Now, one of the techniques which is extremely simple to implement to do this is what is called delta modulation.

(Refer Slide Time: 02:40)

So, it is not a modulation that is usual sense of the word, that is you have a sinusoidal carrier and you put embed the information on to the sinusoidal carrier, in case it is even in the usual sense it is a modulation. Because, the carrier here like in other pulse modulation schemes that we discussed is a train of pulses, so in that sense it is a modulation. Because you are modulating a train of pulses, but the modulation is simply binary in nature, but primary purpose here for this modulation is representation of the analog information into digital form.

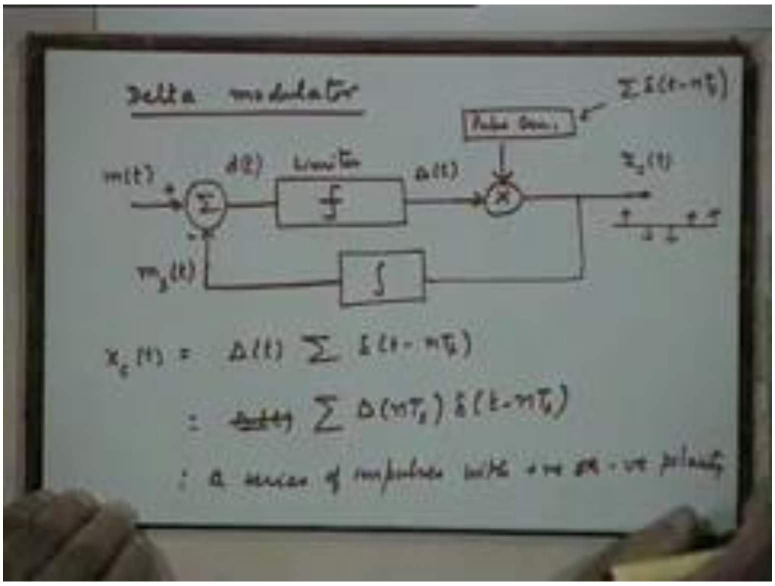
(Refer Slide Time: 03:26)



So, delta modulator essentially converts or you can say encodes any message signal into binary form into a sequence of binary digits or binary symbols to a likely call it. These binary symbols are then represented by the train of positive or negative impulses and that is how they are transmitted. That is of course, the ideal picture, the practical picture of these impulses will be replaced with pulse width of suitable duration, and so these are represented by impulses of positive and negative polarity.

The basic advantage of a delta modulation that, modulation circuits as well as demodulation circuits are extremely simple as compared to the conventional analog to digital converters which you probably would have read something about in your may be digital electronics. I do not know whether you are read that. But, if you have not then you read about it, but there are much more complexes compared to the circuitry of a simple delta modulator, of course there are some pros and cons to that, that we will look at that separately.

(Refer Slide Time: 05:11)



So, the let me draw the block diagram of a delta modulator it is like this, you have the message signal coming in, let us call it m of t, this is compared with in a comparator a reference signal which are called m sub s t, which is essentially some kind of an approximation to m t. If you reconstruct it from the delta modulated signal from the final output, so it is going to be a feedback loop here, this reference signal comes from a feedback path, we have seen that the path is.

So, you look at these two signals, so basically you have a comparator, you subtract these two, so what you get here is a difference between m 3 m, m sub s t, if the difference is positive it will generate a positive output. If the difference is negative you generate a negative output and to do that you have to add a limiter. So, you have a amplitude limiter, which clips the output if it is a positive signal and make it a plus, let us say plus 5 volts or plus 10 volts or plus 15 volts, but have a fixed value.

Let us say plus 5 volt and if it is a negative output it will convert into minus 5 volts, so basically the output, difference output information is encoded into a binary form. You are only looking at a polarity of the difference not the actual value of the difference, is that clear whether the difference is positive or the difference is negative. Whether m t is more than m s t or m t is less than m s t, that is all you are looking at, this signal this is a kind of quantized representation of a difference, very crude quantization where the quantization produces an either plus 1 or minus 1.

The difference is positive it produces a plus 1, if the difference is negative it produces a minus 1 and I am representing this quantized difference signal as delta t, this is where the modulation comes. This modulates or multiplies the pulse train and for the moment we will take this pulse train to be an impulse train for mathematical convenience, so here is a pulse generator.

So, this is your carrier, see in this side there is a PAM going on here pulse amplitude modulation, but the pulse amplitude modulation will lead to pulses which are either positive pulses of fixed amplitude or negative pulses of fixed amplitude, positive impulses or negative impulses of fixed strength. And that is say delta modulation output, so if you have to call the delta modulated output as x carrier is there is some carrier c, x sub c t; this pulse generator gives you a train of pulses like this, impulses delta t minus n T s.

So, there is a pulse rate involved which is 1 by T s, these impulses are coming, and the pulse generator is producing these impulses at the rate of 1 by T s. And therefore, this signal x sub c t is going to be essentially delta t multiplied with this impulse train, which is delta t minus n T s, which you can write as delta t. Or you can take this delta t inside and write this as delta m T s into delta t minus n T sub s, then multiply delta t with delta t, with the t minus n T s. Obviously using the substitute property of the impulse fraction you can write like this.

Now, this is a delta modulated output, now have a feedback path which simply has an integrator and the output of this integrator is precisely this reference signal m s t. So, the reference signal m sub s t is generated from the delta modulated output by passing this output through integrator. And that generates your m s t and that completes the loop and that is your delta modulator, this block diagram represents the delta modulator.

To see whether this is happening in the delta modulator what precisely is a kind of output that you get here, and how what it is doing and also to understand first. Then see how we can recover the signal from the delta modulated output to understand all this, first take the picture which shows precisely what happens for a typical waveform.

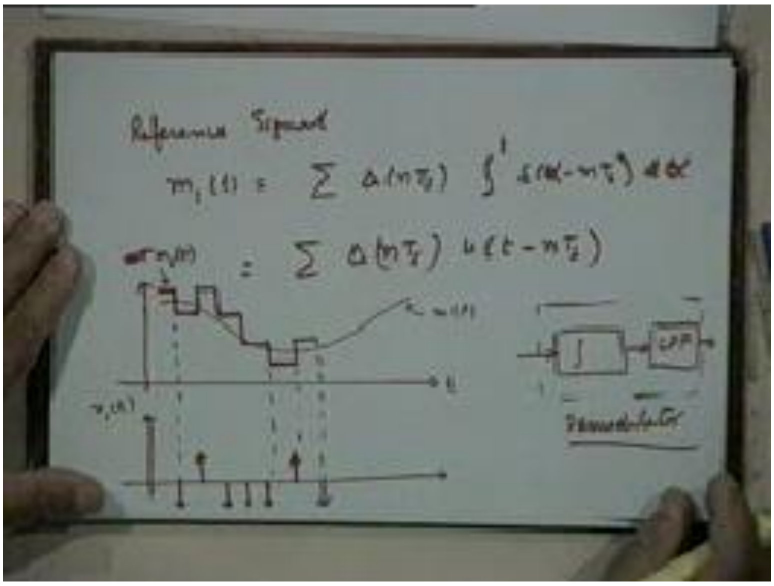
Student: ((Refer Time: 10:23))

Only one bit is being used to encode 1 voltage level here, if you see all we are doing is taking the difference and encoding this difference into either a positive impulse or a negative impulse, single impulse. In that sense a one bit quantization, single bit quantization in that sense, if you are looking at A to D converter context it is different, you do not use multiple number of bits for each sample.

You use a single pulse for a single level or actually binary level for representing the each value of the difference, so x sub this make a comment here, this as you can see the nature of this signal, can you see what is the nature of this signal. If this is a series of positive or negative impulses you got it, because depending on rather delta, what kind of value delta t has output impulse will be either positive or negative.

So, final output is a digital stream a binary stream a two amplitude, two valued stream that is what you want it, you want it in a binary stream, you got a binary stream. From this binary stream you generating this reference signal m s t, so you need to understand what is the nature of this reference signal to understand what is happening. So, this x sub c t is essentially a series of impulses with positive and negative polarity or negative polarity depending on the sign of this difference signal; if I call this difference signal d of t delta t is a quantized version of d of t.

(Refer Slide Time: 12:28)



Now, let us look at the reference signal, reference signal is being generated from this signal how, by integrating this, when you integrate this kind of signal what will you get, this impulse will become a stuff function. So, m sub s t, so let us look at the reference signal, tour m sub s t the reference signal you can write like this, delta n T s, it is a sample of d of t and integrating or integration of delta t minus n T s d t or should we use may be a different variable, let me call this alpha delta alpha minus n T s d alpha, which you can write as delta n T s into u t minus s.

I think we can say that, now can you physically picture what is happening here, you are basically creating a staircase approximation to the message signal m t, can you see that, if not let us draw a picture. Let us say this is a signal, so this is your signal m t and here I will draw the modulated signal x sub c t. Let us assume for the moment that as you can see in any some interval of t sub seconds, the value of m s t is going to be constant.

It basically a step that comes in, where is that here, a step that comes in and that step will the value will remain constant till the next step comes, let us say in the beginning you were somewhere here. The reference signal was looking like this, so this was your m s t and let us look at this point you are comparing m t with m s t, so m t minus m s t is negative. So, this negative the quantize value of delta will become minus 1 and that will produce at the delta modulated output a negative impulse. That negative impulse when it gets integrated will produce a negative step, so basically what it means is that m s t will go through a negative step, let me repeat it if required.

This was less than this, so this was negative after limitation this becomes minus 1, this produces a negative impulse, this negative impulse after t of seconds at this point this time is…, it produces a negative step after integration and that negative step modifies the reference signal from here to here. Now, this value will be hide constant till the next pulse point till the next at this, till this changes, now at this point what do you find that m t is more than m s t, so you will get a positive d of t will be positive.

Now, you will get a positive pulse, do not go by what I have drawn here, so at this point what we have shown you are generating a negative impulse which led to this negative step. And at this point you are generating a positive impulse which generates a positive impulse and at this point that positive impulse generates a step, in the positive direction, in the upward direction and now this process repeats.

Now, what happens at this point we can generate another impulse again, if you compare this and this you will get a negative step and you will reach here, then here, so once again, so this was positive this was negative, this is also negative. At this point still negative, at this point it will be negative positive and so on and so forth. I have not drawn a very good picture perhaps.

So, that is the sequence of binary impulses that you will get and of course, this is a very true picture in the sense that I have taken this step size to be very large, and this sample interval to be rather large. You can make the sample interval rather small and the step also rather small and then, as you can see this picture will more or less approximate closely the actual waveform that you are looking for.

Yes please

Student: ((Refer Time: 18:33))

Yes, there is loss of information

Student: ((Refer Time: 18:37))

We will discuss all these issues, let us go through the process of understanding first, you are right, then you will loss of information, any process which will represent analog information into digital information there will be some loss of information in it. What we think is we like to meet that loss as reasonably small as possible and we will have to see under what conditions will that happen; we will think we need to understand, but let us go through the process first.

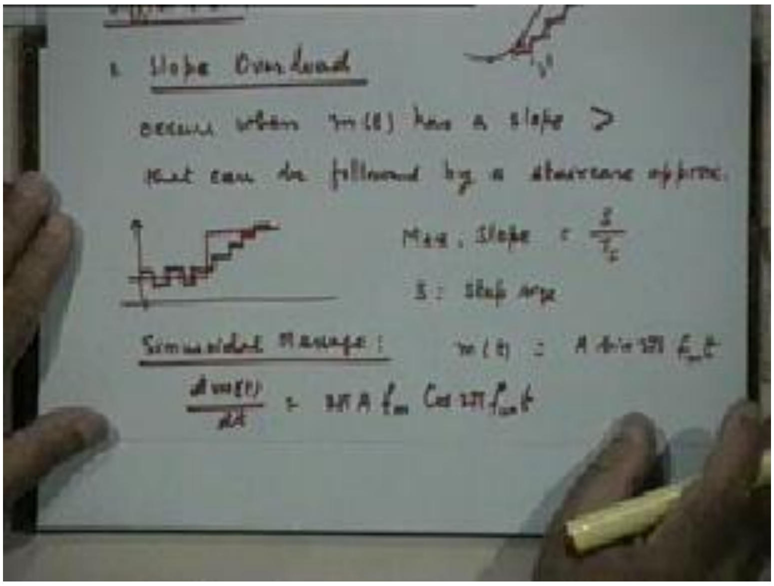
You are absolutely right, so is the process understood, this is how the delta modulator works, so basically the reference signal is staircase kind approximation to the actual signal. And in this way you generate a series of positive and negative impulses and from this description it is also obvious how we should demodulate, how we should demodulate just pass it through an integrator, because that will produce a same staircase approximation of the receiver.

Whatever we doing in the feedback path can be done at the demodulator to produce a same staircase approximation to the message signal m of t, what the thing is. It is a kind of crude approximation and if you want to remove this steps, you should pass it through a low pass filter, to remove the high frequency components which are present in the ((Refer Time: 20:18)). So, the demodulator will essentially give same as this, that you have an integrator followed by a low pass filter, so that is a demodulator, really very simple, any questions so far.

Now, let us see the difficulties with it, there is one of course, there is a difficulty of approximation that is you are losing information, but this loss of information will be easily we can, if example delta step size is very small and your sample interval is also very small. But, in practice you cannot make both these things indefinitely small, because if you do that what will happen, if your step size is too small you see there are some disadvantages.

But, if your this pulse interval sample rate is too large you obviously, have to transmit information at a very large rate, the rate of information transmission will become very large. So, we do not want that also, because that is in a way going to use more bandwidth, so there are those pros and cons. But if you forget about these two issues for the moment, plus some other problems also if you can look at it carefully, one is let me illustrate.

(Refer Slide Time: 22:10)



Let me also give a, so that let us look at two difficulties which are associating with the delta modulator, one is called slope overload, suppose your message signal is changing rather rapidly. Now, there can be a situation that this staircase approximation is not able to track the rapid changes that are happening in the message signal. Every t sub s seconds you are increasing or decreasing this staircase approximation by a step size let us call it s; you are increasing this value by s.

Now, suppose you have the signal are really increasing, let us take for the sake of discussion, suppose the signal are really increasing at a certain rate, what is the maximum rate at which the staircase approximation can attempt to follow that rise. Maximum slope of this rise will be s by t s, you cannot have a staircase faster than this which is dictated by two quantities, one is the step size as, whether is the sample interval T s, so that is your maximum rate at which the signal can be allowed can be allowed to rise.

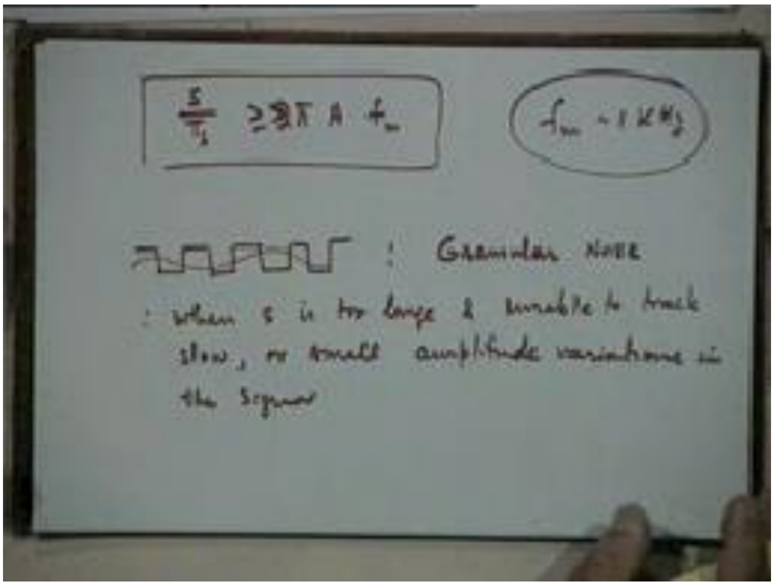
If the signal happens to rise suddenly like that, you will not be able to track these sudden changes in the signal, so for any time interval the slope of your signal increases beyond the maximum slope that the slope can take. There will be the so called this effect slope overload, so this occurs when m t has a slope which is greater than what can be followed by a staircase approximation.

Now, a worst case picture of this, suppose the message signal suddenly it is a step function suppose, it is a worst kind of situation, there is an infinite slope here. So, the staircase approximation has been perhaps like that and beyond this it can only go like that. So, we are total miss this step, it will only go like a ramp, it will not go like a step and here maximum slope that you can tolerate in the message signal is S upon T s, where S is the step size.

Basically, it would be dictated by the amplitude of the impulse that is coming in, the strength of the impulse and you can increase or decrease it if you wish it will depend on the strength of this impulse. You can increase or decrease it, if you want you can put an amplifier here, you can increase or decrease it, but you will increase that way that is one problem with the delta modulator.

In particular, suppose let us discuss this issue for the case of a, I will discuss it for the case of a step signal what happens, suppose instead of a signal you have a sinusoidal message. Then, that is your message signal is of the kind A sine 2 pi f m t, then what is the maximum slope that this can have, 2 pi A f m, so what is the required condition that for this sinusoid we never face the slope overload condition.

(Refer Slide Time: 26:49)



You must have S by T sub s not much greater than, but greater than or equal to 2 pi A f m, if you want to avoid slope overload you should satisfy this condition for a sinusoidal message. So, as you can see for higher frequency messages, the slope overload is more likely to happen than for low frequency messages, but fortunately as typical message signals have a very interesting property.

For example, the voice signal, the amplitude of higher frequencies is typically smaller than the amplitude of the lower frequencies and it is the amplitude and frequency together will determine the slope overload condition. So, it is the product of A into f m which will be important. If a voice signal for example, it is sufficient if you satisfy this condition that some pre chosen frequency, where the amplitude has a certain level which is typically known to be large.

So, for example, the reference frequency that is chosen to avoid this condition for voice signals, actually voice signal is a many frequency components, it is not a sinusoidal signal, but just as a design method. We typically choose f m to be in the neighborhood of 1 kilo Hertz although your actual voice signal goes up to 3 kilo Hertz something, 3 kilo or 4 kilo Hertz.

So, you have to ensure that the slope overload does not occur here and can you please shut this off, what was happening there, this is a class going on, what was the problem, what was the sound.

Student: ((Refer Time: 28:43))

I do not know why you people do this, this is a recording going on, let us proceed further. So, let us basically the point that I was making voice that for voice signals we try to satisfy this condition at some fixed frequency within the voice band which is typically 1 kilo Hertz. This is just as a remark I am making for the design from the design point of view it is not important from the theory point of view.

This is one problem with the delta modulator the slope overload situation, the second one is suppose a signal varies too slowly, very slowly it varies or the amplitude of variation is very small as compared to the step size. Now, let us see what will happen, the alternate steps will be positive or negative, now when you pass this through a low pass filter what will you get, you will get a pass through value.

The average value of these positive and negative steps which is what a low pass filter will produce will be a constant value and you will not be able to track these positions again, so very small amplitude variations also will get killed if your step size is too large. So, we have to do opposite situations if your step size is too small, we are in the danger of having the slope overload condition.

If you want a voice slope overload you must have the value of S to be large, if S is too large you will have the danger of suppressing this situation and very small variations, we will not be able to track them, this kind of situation is called granular noise situation. So, either we have a slope overload situation if the step size is too small or you have a granular noise condition. If the step size is too large, so to choose a value, which is a compromise between these two conditions. So, this happens when S is too large and if you are unable to track very slow or very small amplitude variations, so [fl] is that ok.

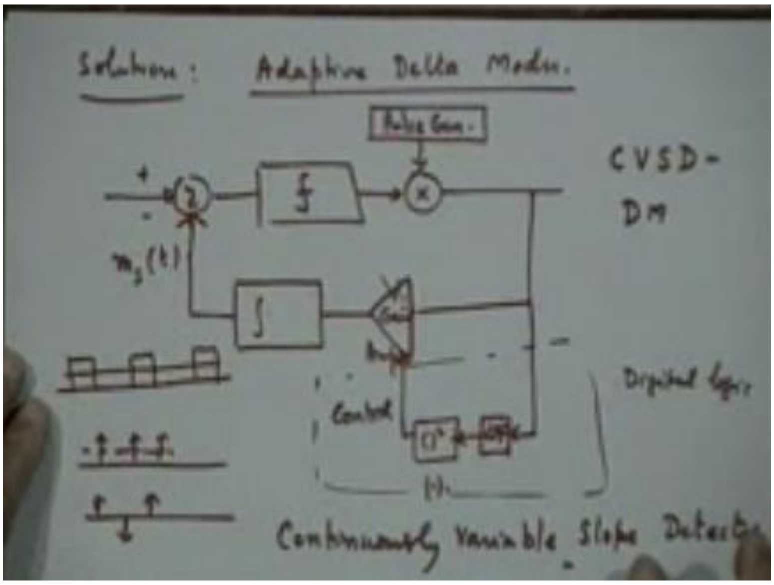
Student: ((Refer Time: 31:59))

Have you got the answers to your questions, so what can we do about these two problems that we have in the case of delta modulator, can you suggest a solution. So, obvious solution from which follows from the discussion we had so far.

Student: ((Refer Time: 32:16))

Any other solution, the key lies in the step size, when we want the step size to be large in the certain conditions and we want the step size to be small under certain conditions. So, if you are able to monitor what kind of conditions exist with the signal and if you are able to modify a step size accordingly, then perhaps you will get a good representation. So, we need what is called a adaptive delta modulator, which is able to track the changes that are happening in the signal and modify it is parameters to make sure that we continue to produce a good representation, so that is the solution.

(Refer Slide Time: 33:10)



So, we can have solution to this problem is go to adaptive delta modulation, now go for adaptive delta modulation and so basically what you want to do by adaptive delta model here, we want to find out what are the slope conditions like. If the slope of the input signal is rather large at in a certain time interval we like to make sure that the step size is increased. If this on the other hand amplitude variations are very small, you should like the step size to be decreased, so that we are able to track this file that is what we want to do. So, how can we do that, how could you find out, is it possible to find this out from the delta modulator output you think?

Student: ((Refer Time: 34:13))

Look at this condition, this is a typical slope overload condition, what would be the delta modulator output in this condition, this m t m t minus m s t value is positive in during this entire interval. So, you will get it constant through a I will put ((Refer Time: 34:35)) positive impulses at the output, so you should get too many positive impulses one after another at the output of the delta modulator. That means, that indicates that is a symptom of the slope overload condition and we can do something about that.

On the other hand, if you face this situation we will always get a positive impulse followed by a negative impulse followed by a positive impulse alternating pulses will be positive and negative. So, we will get a continuous stream of positive and negative impulses alternating, that is a symptom for the ((Refer Time: 35:09)) noise condition. So, we can monitor these two conditions by the nature of the output of a delta modulator and immediately try to take some corrective action and that is the principle of the adaptive delta modulator.

So, if you keep that in mind and then, you look at this picture it is talk to make sense, you have this comparator, this reference signal, this limiter as before everything is same as far as the forward path is concerned, nothing changes. This is a pulse generator, here is an integrator so far everything is fine, but before you feed the input to the integrator, how do you modify a step size. You modify a step size by having an amplifier there which modifies the strength of this impulses or the amplitude of the pulses that are going there.

So, you can have an amplifier, only thing is this amplifier has to be a variable gain amplifier, it cannot be a fixed gain amplifier, if there fixed gain amplifier for the normal delta modulation. So, there is a variable gain amplifier there, variable gain amplifier and this variable gain amplifier the gain is controlled by a control signal. So, this is not the input to the, this is not the input which gets amplified, this is a control input which dictates the gain of the amplifier.

So, this arrow that I have shown here is a control signal, this control signal will modify the gain to the large or small, but of course the signal that has to be amplified is this signal that is coming in, the feedback signal. This control signal has to be now generated from the by looking at the delta modulator output and very simple way of doing this is just pass it through a low pass filter, this will go through a low pass filter followed by a square law defects.

So, I will write it too small, a square law or a magnitude device, see what is happening, what we were saying is, if there too many positive impulses or too many negative impulses coming in a row. So, either we have a large positive slope or a large negative slope, so what will happen, what would be the low pass filter output, the low pass filter output will show continuous. Let us say if you have let us say large number of positive impulses coming the average value will be some large DC value.

I mean value of few pulses were few pulses will be some large positive or negative DC value depending on the slope is in the positive direction or in the negative direction. So, we just need to monitor that value, so this passing through a low pass filter which will average out this sequence of positive impulses. Because the DC value associated with that have some fixed time interval a constant average value.

We look at the average value, if that average value is magnitude of the average value is large decrease here, so this control sequence has a large voltage. This variable gain amplifier here should be designed to produce a large gain, you want to produce a large gain, and we want to increase the step size. On the other hand, if you have this situation of positive or negative impulses coming alternately this control voltage will be, this low pass filter output will be small.

And what you want now is this control signal should decrease the gain, so as to keep the step size small, so that is the principle. Of course you can increment this control value also using appropriate digital logic driver analog circuit. For example, you can actually have a digital logic which can track whether a few successive pulses are of the same sign or different sign and produce a control signal based on that.

So, this can be replaced by a suitable digital logic as well you should do this. Let me complete this, you should get things like this, this particular kind of adaptive delta modulator is called a continuous variable slope detector delta modulator, CVSD delta modulator.

Student: What is the full form?

Full form is Continuously Variable Slope Detector, CVSD.

Yes

Student: ((Refer Time: 40:47))

We have large number of positive pulses 3 or 4 successive positive pulses. During that time interval see what is the low pass filter doing, basically carries out some kind of averaging operation over some time interval. If you look at the impulse response of a low pass filter and then, look at the combination operation, essentially it is some kind of a averaging operation that you do in a short interval of time.

And that short interval of time if a few positive pulses come it will produce an output which is average of these values. Roughly, roughly this kind of effect of the low pass filter the precise actually it is given by nature precise of the low pass filter. So, if this happens you will get a reasonably large average positive value and that serves as a signal to the amplifier that I must increase again. So that again if increases, means the step size will increase.

Student: ((Refer Time: 42:04))

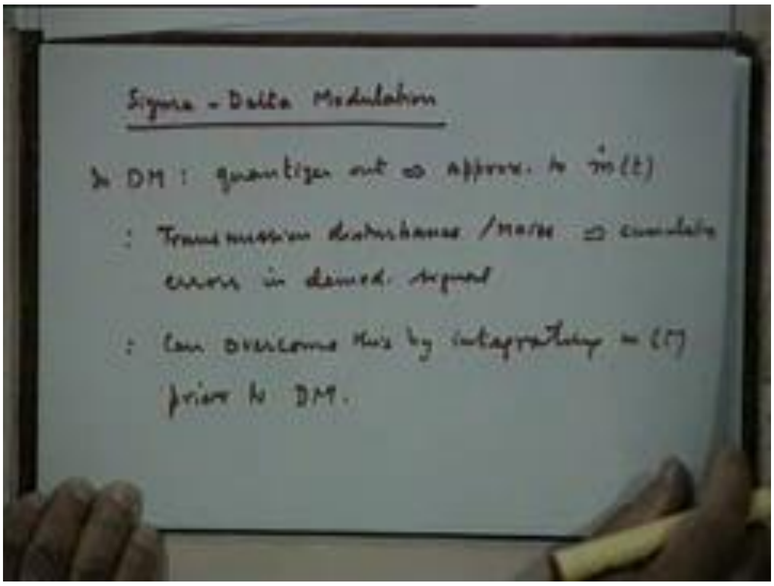
((Refer Time: 42:14)) that is a very important question, what is the other advantage of this we have made this, rather than the way [fl] is saying.

Student: Modular

No, very simple remember this is also a demodulator, this will now approximate the m s basic waveform much better at this approximation is being derived for the delta modulator output. So, your feedback path whatever it is also depends on delta demodulator, your demodulator circuit now becomes this, so you get the answer to your question, that is why you would rather derive this information from the delta modulator itself. So, that whatever I am doing here becomes my module for what I should do to the demodulator.

So, it is a good question that you asked and your answer with this coming to that anyway, so your demodulator circuit is precisely this feedback path. Because, this feedback path would essentially reconstructing the message waveform for you in a better approximation, because ((Refer Time: 43:37)).

(Refer Slide Time: 43:48)



One last concept in the context of delta modulation is a very important variation of delta modulation which is called sigma delta modulation; these are very interesting term delta and sigma. As you can see the circuitry is extremely simple and all you need is a comparator, a limiter and look at the circuit diagram, what are the kinds of components you need, adder, subtractor, limiter extremely simple to make.

A multiplier in which one of the inputs is a pulse, extremely simple to make, these are very simple things to do, so that is why delta modulator was a very popular method at one time and it again has become very popular these days. Now, in the delta modulator what we are discussed so far, if you just look at it purely from an intuitive point of view.

Suppose, you have to roughly say what is the delta the x sub c t that you are producing, the delta modulator output that you are producing what does it really represent, does it represent the signal directly or indirectly, indirectly. In fact, it represents the difference successive differences in the signal, the positive and negative impulses that are coming they are representations of the successive differences between the signal, whether the signal has increased or decreased from it is previous value.

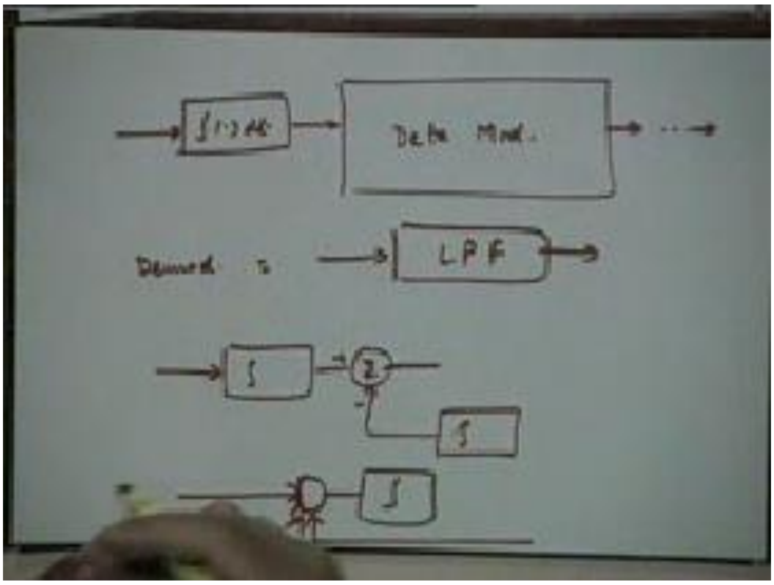
Essentially that is what it is able to monitor, so what is when you say successive difference, it is something proportional to the derivative of the signal, because the time interval is fixed. So, in a way the delta modulator output is a representation of the derivative of the message signal in a very crude sense, so in DM the quantizer output that is delta of t equals, you could say based on this argument that I have given is an approximation to m dot t rather than m t, would you agree with this statement.

Now, is that a good thing or a bad thing from the noise point of view, if there is any noise it will get enlarged. So, there is a transmission or disturbance somewhere it will get accumulated, because of the fact that transfer function is omega square, transfer function magnitude say omega square. So, any transmission disturbance or noise in the system anywhere would lead to let us say cumulative errors in the demodulation signal, think about that, therefore now how can you overcome this.

We can overcome this by precisely using the same argument, we choose to understand why this is representation of m dot t, so let us not try to approximate m dot t just try to approximate m t itself, how can we do that. Feed into the delta modulator not m t directly, but it is integrated version, so that if you do that that is what leads to a sigma delta modulator. So, and there is some basically we can overcome this by integrating m t prior to delta modulation and there are some additional benefits if you do that.

The low frequency component that the few emphasize in the integrator which is nice and there is additional correlation between adjacent samples. And actually speaking, if you think about it delta modulator exploits the correlation between adjacent samples, it is a good representation, because successive differences. So, that correlation becomes much stronger, now because of the integration, but these are things are ((Refer Time: 48:35)) too much time here.

(Refer Slide Time: 48:39)



So, basically a sigma delta modulation looks like this, you have an integrator and you have the normal delta modulator and now tell me what would be your demodulator now. If I want to reconstruct this I must have the integrator followed by the low pass filter, but I am not interested in this I am interested in this, so I could differentiate the signal. So, integrator followed by a differentiator is I do not need to do anything, so demodulator is simply a low pass filter, very simple to demodulate.

So, instead of a binary representation everything is same, but we get both the advantages, you simplify demodulator and you remove the problem of being proportional to derivative. Also you can simplify this itself, if you think about it this integrator will not be outside this loop; in fact you see there are two integrators. One is here and where is the? One is here and you are just adding here adding things here, I can remove this here and bring this ((Refer Time: 50:08)) simply one integrator here, that looks for both the things.

So, my feedback path is simple straight line, so my final diagram on the sigma delta modulator becomes how it would be, are you with me ((Refer Time: 50:33)). That is a sigma delta modulator; that is sigma is a simplified notation one uses for this and the demodulator is simply a low pass filter.

So, we conclude our discussion on delta modulation here today, but I am not able to give the delta modulation which I would have like to do is noise performance analysis of delta modulator, so that I am leaving as again self-reading exercise.

Thank you very much.