okay so yesterday we looked at the uh importance of representing analog information into
digital form and then communicating this information into digital form right because we
uh 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 if you want to just transmit the information in the analog
form right
of course the key to this better performance is the use of repeaters
regular regenerative repeaters which at intermediate points will clear up the signal and
retransmit it retransmit the ((clean…01:48)) cleaned up signal and that’s that’s the reason
((manifit…)) of improved performance at loose if you transmit uh digital information
rather if you transmit information in the analog form right
so the big issue that arises how do you how do you convert your analog information if
you want to transmit into digital form right and towards the end of our course we are
basically going to discuss two techniques discuss two techniques which we will convert
analog information into a binary digital representation right which is something uh
already already knowing the context of A to D converters but we will look at it from from
the communication theory point of view right
now what are the techniques which is extremely simple to implement to do this is what is
called delta modulation right
(Refer slide time on 02:42)
so it is not a modulation that’s usual sense of the word uh that is you have a sinusoidal carrier and you uh put embed the information on to the sinusoidal carrier but in case its ((also…)) 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 uh so in that sense it is a modulation because you are modulating a train of pulses right but the modulation is simply binary in nature but primary purpose here for ((pulse…03:15)) modulation is representation of the analog information into digital form okay
so delta modulator uh essentially converts or you can say encodes any message signal into binary form into a sequence of binary digits or binary symbols let me call it these binary symbols are then represented by the train of positive or negative impulses and that is how they are transmitted right that is of course the ideal picture the practical picture of these impulses will be replaced with pulse width of suitable ((…)) right
so these are represented by uh impulses of positive and negative polarity (Refer slide time on 04:41)
the basic advantage of a delta modulation is 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 uh may be digital electronics
I know you have 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 right of course there are some pros and cons to that that we will look at that separately so the let me draw the block diagram of a delta modulator its like this you have the message signal coming in lets call it m of t this is compared with in a comparator with reference signal which are called m sub s t right which is uh essentially some kind of an approximation to m t if you reconstrcut it from the delta modulated signal from the final output so its going to be a feedback loop here this reference signal comes from a feedback path right we have seen that the path is so you look at the uh 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 three and m sub s t right
if the difference is positive it will generate a positive output
if the difference is negative it will generate a negative output and to do that you have to add a limiter
so you have a amplitude limiter right which clips the output if it is a positive signal and make it a a plus lets say plus five minutes or plus ten minutes or plus fifteen minutes but have a fixed value
lets say plus five volt and if it’s a negative output it will convert into minus five volts
so basically the output difference output information is encoded into a binary form right 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’s all you are looking at
this signal this is a kind of uh you know uh quantized representation of a difference very crude quantization where the quantization produces a either plus one or minus one right the difference is positive it produces a plus one
if the difference is negative it produces a minus one and I am representing this quantized difference signal as delta t right
this now 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 right
so here is a pulse generator
so this is your carrier
see in this side PAM going on here pulse amplitude modulation
the pulse amplitude modulation will lead to pulses positive pulses of fixed amplitude or negative pulses of fixed amplitude
positive impulses or negative impulses of fixed strength
is that okay and that’s what 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 one by $T$ right
this impulses are coming
the pulse generator is producing these impulses at the rate of one by $T$ right and
therefore this signal $x_{xct}$ is going to be essentially delta $t$ multiplied with this
impulse train which is delta $t$ minus $nT$ which you can write as delta $t$ or you can take
this delta $t$ inside and write this as delta $mT$ into delta $t$ minus $nT$ right
then multiply delta $t$ with delta $t$ delta minus $nT$
obviously using the substitute property of the impulse you can write like this okay
now this is a demodulated delta modulated output
now have a feedback path which simply has an integrator right and the output of this
integrator is precisely this reference signal $m_s t$
so the reference signal $m_{st}$ 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’s your delta modulator
this block diagram represents the delta modulator

(Refer slide time on 09:55)
[student: when we are capturing the that how many bits are being used to encode one voltage level]

uh only one bit is being used to encode one voltage one 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 right in that sense a one bit quantization right single bit quantization in that sense if you are looking at A to D converter context it is different

you don’t use multiple number of bits for each sample

you use a single uh pulse for or a single level or actually binary level for representing the each value of the difference okay

so x sub this make a comment here

this is a see 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 right you got it because ((depending on the…11:28)) 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’s what you want it

you want it in a binary stream

you got a binary stream

from this binary stream you getting this reference signal m s t

so you need to understand what is the nature of this reference signal to understand what is happening right

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 right

(Refer slide time on 12:22)
now let's look at the reference signal
reference signal is being generated from the signal right
isn't it
how
by integrating this
when you integrate this kind of signal what will you get
this impulse will become ((just…)) a function right
so \( m_{s} \)
so let's look at the reference signal
your \( m_{s} \) the reference signal you can write like this
\( \delta n T_s \)
it is a sample value of the \( n \)th sample of \( d \) of \( t \) and integrating or integration of \( \delta t \) minus \( n T_s \) \( dt \) 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 \( um \) yes I think we can say that right
now can you physically picture what is happening here um
um you are basically creating a staircase approximation to the message signal \( m_t \)
can you see that okay
if not let's draw a picture
[student coughing]
let us say this is a signal right
this is your signal m t and here I will draw the modulated signal x sub c t

lets 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

isn’t it

it basically a step that comes in

sorry this is here

a step that comes in and that step will the value will remain constant till the next step comes right

let us say in the beginning you were somewhere here

the reference signal was looking like this

so this was your m s t right and lets look at this point you are comparing m t with m s t

so m t minus m s t is negative right

so this negative the quantize value of delta will become minus one and that will produce at the delta modulated output a negative impulse

that negative impulse when it gets integrated will produce a negative step right

so basically what it means is that m s t will go through a negative step

is that clear

let me repeat it if required

this was this was less than this

so this was negative

after limitation this becomes minus one

this produces a negative impulse

this negative impulse after t t of seconds this this this at this point this it produces a negative step right after integration and that negative step modifies the reference signal from here to here

is that clear

now this value will be ((hide…)) constant till the next pulse pulse point till this changes

now at this point what do you find that m t is more than m t s m s t

so you will get a positive

d of t will be positive

now you will get a positive pulse
don’t 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 right and at this point you are generating a positive impulse which
generates a a positive impulse right 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 an other impulse again right
isn’t it
if you compare this and this you will get a negative step and you will reach here
then here right
so once again so this was positive this was negative
this is also negative
at this point still negative right
at this point it will be negative positive and so on so forth
I have not drawn a very good picture perhaps
so that’s 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 right 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
as you can see this picture will more or less approximate closely the actual waveform that
you are looking for
yes please
[student: sir will there be any loss in information]
yes there is loss of information
[student: time interval ((( )))]
we will discuss all these issues
lets go through the process of understanding first
you are right
there will be a loss of information
any process which will represent analog information into digital information there will be
some loss of representation loss of information in it right
what we think is we like to meet that loss as reasonable reasonably small as possible right
and we will have to see under what conditions will that happen
we will think we need to understand but lets go through the process first
you are absolutely right
okay so uh 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 right 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 do 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 you if you want to remove this uh steps you
should pass it through a low pass filter to remove the high frequency components which
are present in the (( 2018))
is that clear
so the demodulator will essentially give same as that you have an integrator followed by
a low pass filter
so that’s a demodulator
(Refer slide time on 20:46)
really very simple
any questions referred
all right
now lets see the difficulties with it
there is one of course there is a difficulty of approximation that is uh you are losing information right
but this loss of information will be easily be ((can…21:08)) 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 uh if your step size is too small you see there are some disadvantages but if your ((impu…)) this this pulse interval sample rate is too large right you obviously have to transmit information at a very large rate
the rate of information transmission will become very large right
is that clear
so we don’t want that also because that is in a way going to use more bandwidth right
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 uh okay let me illustrate
((let me also give… 22:08))
lets look at two difficulties which are associating with the delta modulator
one is called slope overload  okay
suppose your message signal is changing rather rapidly okay
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 set of seconds you are increasing the you are increasing or decreasing this staircase approximation by a step size lets call it S right

you are increasing this value by S

we suppose suppose you have the signal are really increasing

lets take for the sake of discussion

suppose the signal are really increasing at a certain rate

what is the maximum rate at which you can uh at which the staircase approximation can attempt to follow that rise

maximum slope of this rise will be S by t s right

you cannot have a staircase faster than this right which is dictated by two quantities

one is the step size as

where is the sample interval Ts so that is your maximum rate at which the signal can allow can be allowed can be allowed to rise

if the signal happens to rise suddenly like that right

you will not be able to track these sudden change in the signal right

so for any any time time interval the slope of your signal increases beyond the maximum slope that the slope can take right

there will be the so called this effect slope overload right

so occurs this occurs when m t has a slope which is greater than what can be followed by a staircase approximation

now a worst uh case picture of this suppose the message signal suddenly uh it is a step function suppose

it is a worst kind of situation

there is a infinite slope here

so uhthe staircase approximation has been perhaps like that right and beyond this it can go only like that

so you total is 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 \( T \) where \( S \) is the step size basically it will be dictated by the amplitude of the impulse that is coming in isn’t it 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 right but you will increase ((that way… )) that’s one problem with the delta modulator is it clear in particular suppose lets 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 right then that is your message signal is of the kind \( A \) sine two pi \( f \) \( m \) \( t \) all right then what is the maximum slope uh that what is the maximum slope that this can have two pi \( A \) \( f \) \( m \) right so what is the required condition that for this sinusoid we never face the slope overload condition (Refer slide time on 26:43)
you must have um \( S \leq T_{sub} \) not much greater than but greater than or equal to two \( \pi \)
\( A_{f m} \)

if you want to avoid slope overload you should satisfy this condition for a sinusoidal message

so as you can see for uh for higher for higher frequency messages right the slope overload is more likely to happen than for low frequency messages

but fortunately as you know 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 if you satisfy this condition that some pre chosen frequency right where the amplitude has a certain level which is typically known to be large right

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 as a just a design method

we typically choose \( f_{m} \) to be in the ((major… )) of one kilo hertz although your actual voice signal goes up to three kilo hertz something okay three or four kilo hertz right

so uh you have to ensure that the slope the slope overload does not occur here and uh

excuse me can you please shut this off

what was happening there

this is a class going on

what was the problem

what was the sound

I don’t know why you people do this

this is a recording going on um

okay lets proceed further
all right so uh lets uh basically the point that I was making was that uh for voice signals we try to satisfy this condition at some fixed frequency within the voice band which is typically one kilo hertz right
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 okay this is one problem with the delta modulator the slope overload situation the second one is uh suppose a signal varies too slowly right very slowly it varies or the amplitude of variation is very small as compared to the step size right	now let us see what will happen the alternate steps will be positive or negative isn’t it
now when you pass this through a low pass filter what will you get you will get a(constant value the average value of this positive and negative steps which is what a low pass filter will produce right 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 right 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 uh situation is called granular noise situation right so uh 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 right so the uh choose a value which is a compromise between these two conditions [student coughing]
so this happens when S is too large and if you are unable to track very slow or very small variations
small amplitude variations
so Venkat is that okay
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
(Refer slide time on 32:10)

so obvious solution from which follows from the discussion we had so far
[student: ((analytic…)) technique]
any other solution
the key lies in the step size isn’t it
when uh we want the step size to be in the large in 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 ((mod…)) modify a step size accordingly right 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 its parameters to make sure that uh we continue to produce a good representation right
so that’s the solution
so we can have solution to this problem is go to adaptive delta modulation
now go for adaptive delta modulation okay and so basically what you want to do by adaptive delta model here
we want to able to 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 [student coughing] increased
if this if 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 right
that’s what we want to do
so how can we how can we do that
how could you find out
is it possible to find this out from the uh delta modulator output you think
[student: sir if we have a continuous stream of]
look at this condition
this is a slope typical slope overload condition
what would 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 it 34:36)) 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’s 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’s a symptom for the uh ((interior…35:09)) noise condition
so we can uh monitor these two conditions by the nature of the output of a delta
modulator and immediately try to take some corrective action right and that’s the
principle of the adaptive delta modulator right
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 uh 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 the ((… 36:01)) is feed the input to the integrator
how do you modify a step size
you modify a step size by having a amplifier there right which modifies the strength of
the (( 36:08)) pulses right or the amplitude of the pulses that are going there
isn’t it
so you can have a amplifier
only thing is this amplifier has to be a variable gain amplifier
it cannot be a fixed gain amplifier right
if (( )) fixed gain amplifier for the normal delta modulation right 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 right
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 right
this control signal has to be now generated from the by looking at the delta modulator
output
is it clear and a 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 (( ))
[student: coughing]
so I will have (( )) a square law
see what is happening
what we were saying is
if there too many positive impulses or too many negative impulses coming in a row right
so either we have a large positive slope or a large negative slope
so what can happen
what would be the low pass filter output
the low pass filter output will show uh continuous uh lets say if you have lets say large
number of positive impulses coming the average value will be some large dc value
isn’t it
(I mean value of the… 38:16)) few pulses you have a few pulses
there will be some large positive or negative dc value depending on the slope is in the
positive direction or in the negative direction right
so we just like to monitor that value
so this passing through a low pass filter which will average out this positive sequence of
positive
so there is a sequence of positive impulses right 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
sorry large a large gain
we want to increase the step size right
on the other hand if you have this situation of uh positive or negative impulses coming
alternately this control voltage will be
this low pass filter output will be small
what you want now is this control signal should decrease the gain so as to keep the step
size small
so that’s the principle right
of course you can increment this control value also using appropriate digital logic driver
analog circuit right
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 right and produce a control
control signal based on that
so this can be replaced by a suitable digital logic as well
you should get 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 right
@student: what is the full form
okay full form is continuously variable slope detector CVSD right
yes
@student: (( )) too many pulses are detected on a signal
we have large number of positive pulses three or four 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 now 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 right and that short interval of time if a few positive
pulse has come it will produce an output which is average of these values right roughly
roughly this kind of effect of the low pass filter the precise nature of the low pass filter
right
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 right
@student: sir wont it will be better taking the controller before the limiter
that would actually difference between m s (( ))
it will (( )) work with something okay
that’s a very important question
what’s the other advantage of this we have made this rather than the way venkat is saying
@student: modular
no very simple remember this is this is also you are demodulator
isn’t it
this will now approximate the m s basic waveform much better at this approximation is being derived for the delta modulator output right 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 [student : yes isir] 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 is it clear so it’s a good question that you asked and your answer with this coming to that anyway so your demodulator circuit is precisely this feedback path [student coughing] because this feedback path would essentially reconstructing the message waveform for you in a better approximation because ((…43:37)) all right (Refer slide time on 43:37) good one last uh 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 and right and these are uh as you can see
the circuitry is extremely simple and all you need is a comparator a limiter and uh look at
the circuit diagram
what are the kind 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 right
all right
now in the delta modulator that we 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 ((modulate…)) 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
isn’t it
the positive and negative impulses that are coming they are they are representations of the
successive differences between the signal whether the signal has increased or decreased
from its previous value
essentially that is what it is able to monitor
so what is what uh
when you say successive difference its something proportional to the derivative of the
signal because the time interval is fixed right
so in a way the delta modulator output is a representation of the derivative of the message
signal in a very crude sense right
so in DM the quantizer output that is delta of t equals (()) argument that I have given is
an approximation to m dot t rather than m t
would you agree with this statement um
now is that a good thing or a bad thing from the noise point of view um
that is if there is any noise it will get enlarged right
so uh so there is a transmission or disturbance somewhere it will get accumulated because
of the fact that transfer function is omega square right
transfer function magnitude ( ) is omega square
so uh any transmission disturbance or noise in the system anywhere would lead to uh lets
say cumulative errors in the demodulation signal
think about that
this therefore now how can you overcome this
we can overcome this by precisely using the same argued 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 its integrated version right
so that’s the if you do that that’s what leads to a sigma delta modulator all right
so ( ) basically we can overcome this by integrating m t prior to delta
modulation and there are some additional benefits if you do that
the basic ( ) 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 right uh it is a good representation
( ) because successive differences all right
so that correlation becomes much stronger now because of the integration but ( )
so basically a sigma delta modulation looks like this
you have an integrator and you have the normal delta modulator right 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 don’t need to do anything right
so demodulator is simply a low pass filter
very simple to demodulate
so instead of a binary representation everything is same but uh we get both the advantages
you simplify demodulator and you remove the problem of uh being proportional (( ))
also you can simplify this 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 other one
one is here right and you are just adding here adding things here
I can remove this here and bring this
(( )) simply a one integrator here right
that looks for both the things
so my feedback path is simply simple straight line

(Refer slide time on 50:21)

so my final diagram on the sigma delta modulator becomes how it would be
that’s it
right
that’s a sigma delta modulator
that’s sigma is a simplified notation one uses for this and the demodulator is simply a low pass filter okay
so we conclude our discussion on delta modulation here today but I am not able to give the delta modulation which is would have like to do is noise performance analysis of delta modulator
so that I am leaving as again self reading exercise
all right
thank you very much