Course on Principles of Communication Systems – Part 1
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Lecture 47
Module 8
Differential Pulse Coded Modulation (DPCM), Quantization and Signal Reconstruction, Schematic Diagrams

Hello, welcome to another module in this massive open online course. So we are looking at different forms of pulse modulation we have looked at pulse amplitude modulation we have looked at delta modulation, alright which is based on encoding the differences which is a differential modulation scheme. So in this module let us start looking at another pulse modulation scheme that is differential pulse coded modulation or DPCM, okay.

So we start a new module in which we want to start looking at differential pulse coded modulation this is differential pulse this is differential pulse coded modulation, correct as the name implies and this is abbreviated as (DPCM) for Differential Pulse Coded Modulation and this is based on the principle that for instance when you have natural signal such as video signals and audio signals they have a very high level of correlation.

So rather than encoding the samples similar to delta modulation one can encode the differences between the samples but it is more sophisticated than delta modulation, alright.

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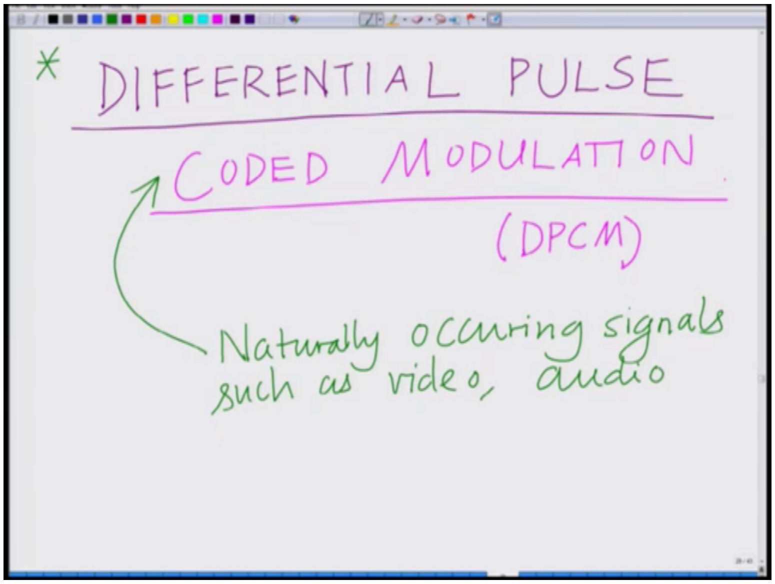

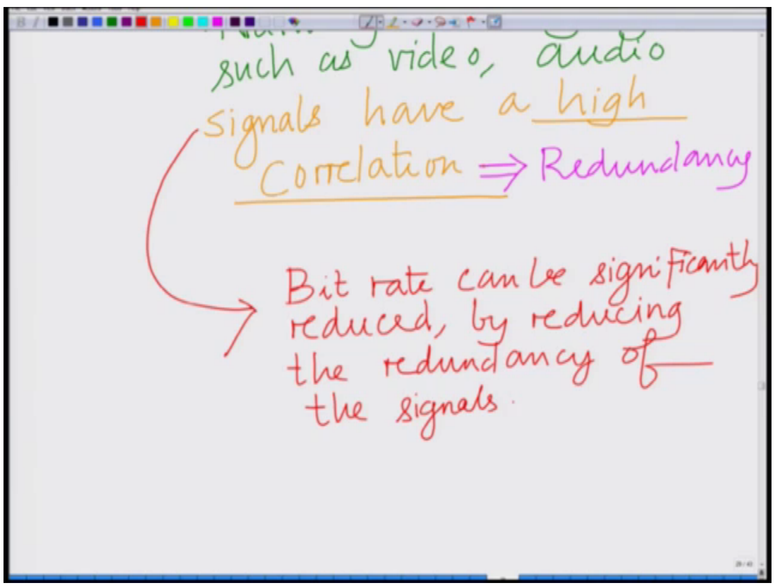

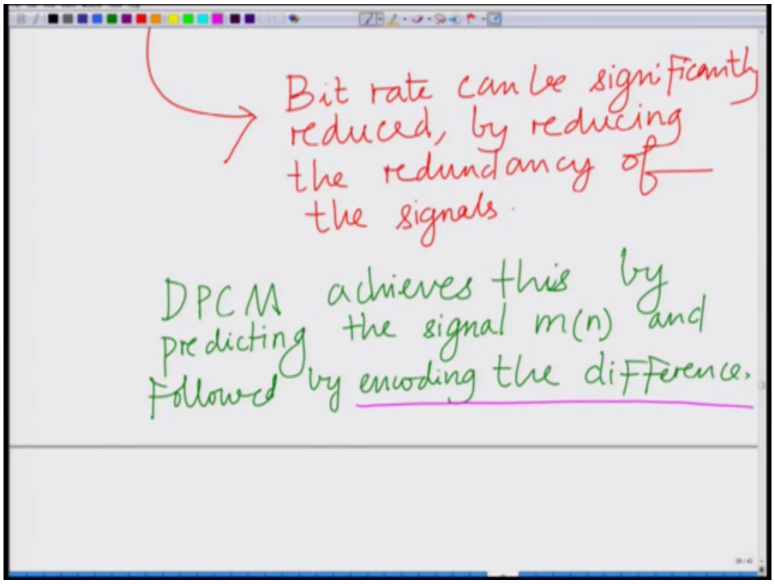

So the key principle behind that is that naturally occurring signals such as video and audio signals have a very high this have a very high this are very highly correlated, correct? Hence, one can so the bit rate so this have very redundancy high correlation which implies also that this have a very high redundancy, correct?

So high correlation also implies that, so these have a very high redundancy which implies that the bit rate can be therefore the bit rate can be significantly reduced by reducing the redundancy, right? So the bit rate can be simply significantly reduced bit rate can be significantly reduced by reducing the redundancy of the so they have a lot of they are correlated which leads to a lot of redundancy, alright. So the bit rate, right which means the bit rate there is a number of bits required to encode each sample can be significantly reduced by reducing the redundancy of this signal, alright and this is what DPCM tries to achieve, okay.

And DPCM the way DPCM achieves this is reducing the redundancy DPCM employs so achieves this or reduces the redundancy achieve this by predicting the predicting the signal m[n] by predicting the signal sample m[n] and followed by encoding the difference. So what we have is and we encode the difference that is the differential modulation aspects, so what we have is if you really look at it we have a signal with lot of redundancy, alright a lot of redundancy alright and this leads to predictability of the signal because of this redundancy one can predict the signal, alright.

And therefore, rather than quantizing the entire signal one can predict the signal look at the difference between the signal sample and the prediction and then encode the difference that results in a significant efficiency, a significant improvement in the quality of the quality of the quantization quality of the compression, okay.

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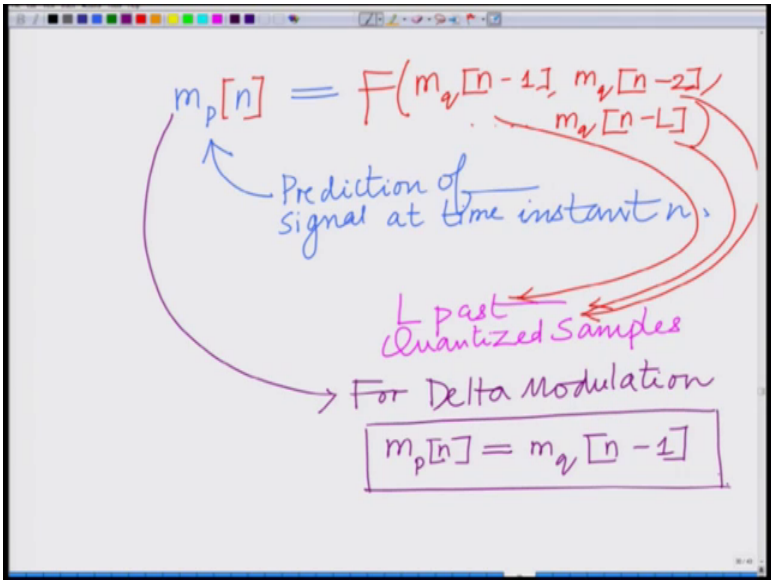

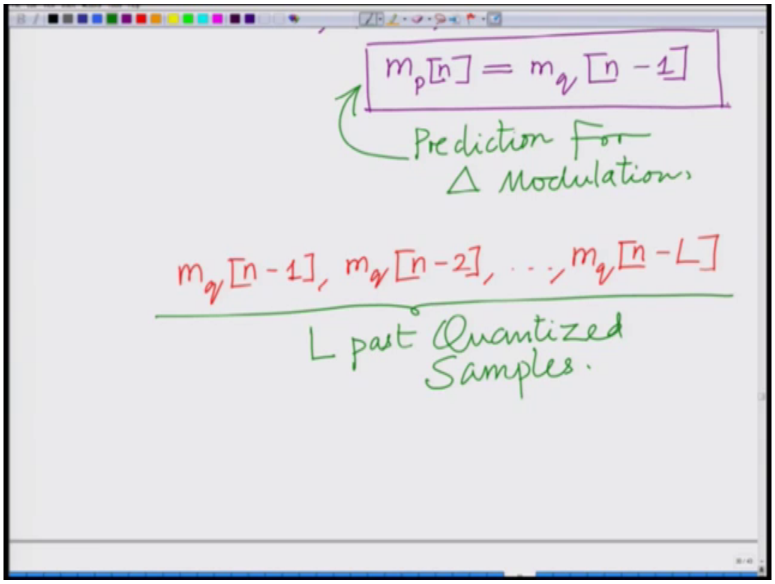

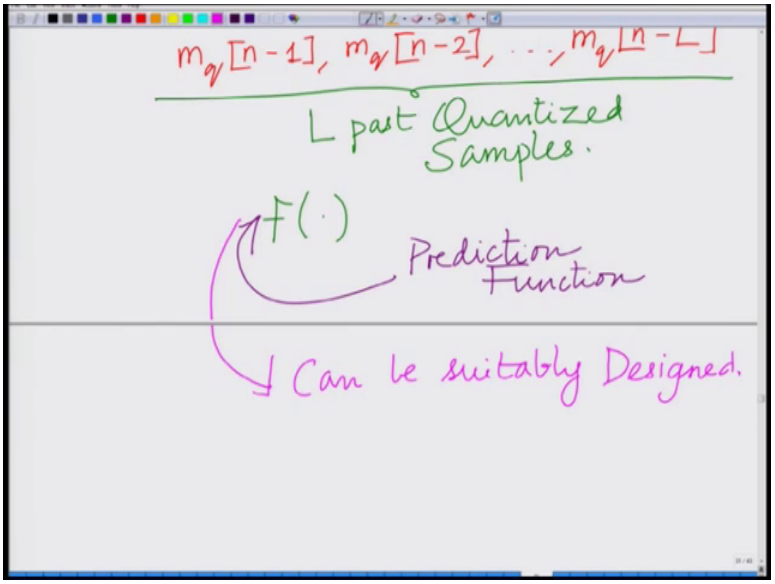

So what we are doing is basically we are deriving a prediction of the signal, so mp(n) this is a predicted sample of the signal at time (ins) this is a prediction of the signal at time instant n this is obtained as F(mq[n minus 1], mq[n minus 2], so on up to mq[n minus L]).

So what we are doing is basically we are so what we are doing is basically we are using L past sample so if you look at this mq[n minus 1], mq[n minus 2], mq[n minus L] these are the L past quantized or basically reconstructed samples, okay these are the L past samples so we are using the L past reconstructed samples to predict the signal at time instant n. Then we subtract this prediction from m and encode the difference, alright.

Now, in delta modulation this prediction function is very simple mp[n] is (sim) is simply mq[n minus 1] that is the last quantized sample, okay. So for delta modulation now if you remember delta modulation for delta modulation we use a simple prediction function that is mp[n] is simply mq[n minus 1] this is the prediction function for this is your prediction function for the delta modulation mp[n] equals mq[n minus 1], okay so this is the prediction form delta modulation DPCM generalizes it.

The prediction cannot prediction need not necessarily be simply mq[n minus 1] but one can use not just one sample but past L quantized samples to improve the quality of prediction, therefore the better the quality of the prediction, right? The better the quality of prediction the better is the quantization higher is the efficiency of quantization so we have the prediction, alright. So we are using the L past samples quantized or reconstructed samples your mq[n minus 1], mq[n minus 2], mq[n minus 1] these are L these are L past quantized samples not just past samples these are L past quantized samples these are the L past quantized samples, alright.

F the function F is your prediction function, correct we are using the L past quantized samples in the function F F equals there are ways to construct the optimal prediction function, okay this prediction function can be suitable design the prediction function has to be appropriately designed can be the prediction F is not fixed but it can be suitable decide various (())(10:43) that depends on the appropriate signal it takes the signal characteristics more importantly the statistical properties of the signal into consideration to appropriately design the best prediction function, alright.

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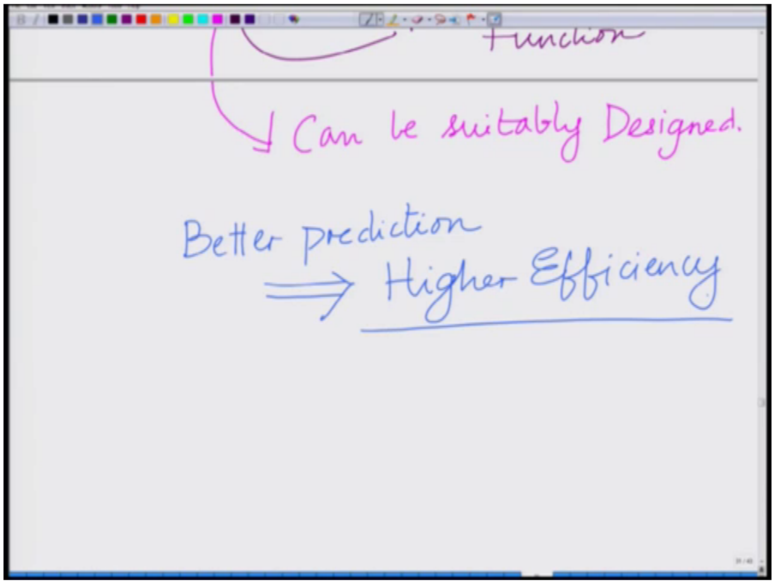

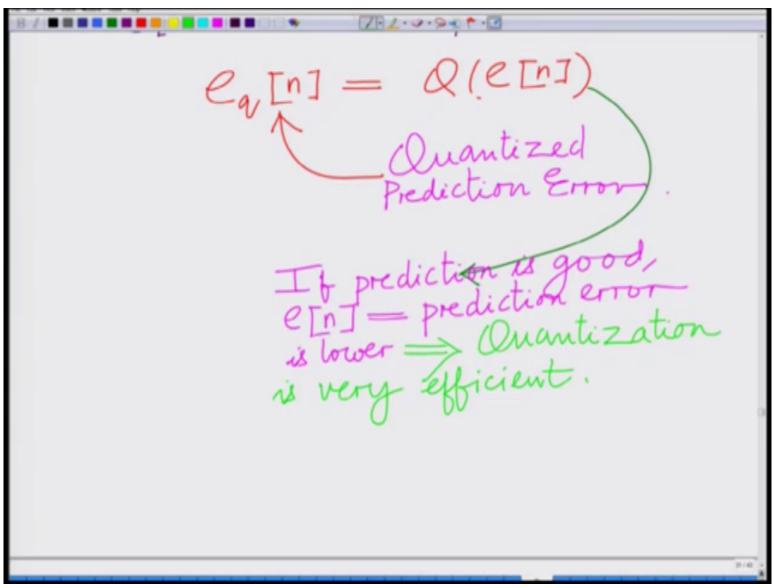

Now, better prediction implies a higher efficiency the better the prediction the higher (effi) the efficiency better prediction implies a higher efficiency, okay that is the bottom line in DPCM. Now how do we use this prediction in DPCM? In DPCM what we do in differential pulse coded modulation we have the signal m[n] signal sample m[n] from this signal sample we subtract its (())(11:46) prediction mp[n] that gives rise to e[n].

So e[n] so at m at every time instant n we have a prediction mp m of the signal. Now from m[n] we subtract this prediction mp[n] we get e[n]. So e[n] is the prediction error, okay so this e[n] is the prediction error you can think of this as a now this prediction error is quantized, so now what we have is we quantize this prediction error to get the quantized error Q(e[n]) this is your quantized prediction error you get the quantized prediction error, okay.

Now better the end prediction lower the prediction error the better the quantization prediction error is lower which means if its dynamic error range is lower, than the quantization can be made more efficient, right? For for the same number of bits if the (dyna) dynamic range is lower than the quantization error is lower, correct. So if the prediction is good, right if the prediction is good means mp[n] is very accurate representation of m[n] e[n] which is equal to the prediction error is lower this implies, right this implies the quantization this implies that the quantization is very efficient.

Therefore we need very accurate prediction, alright? In DPCM we need very accurate prediction, okay.

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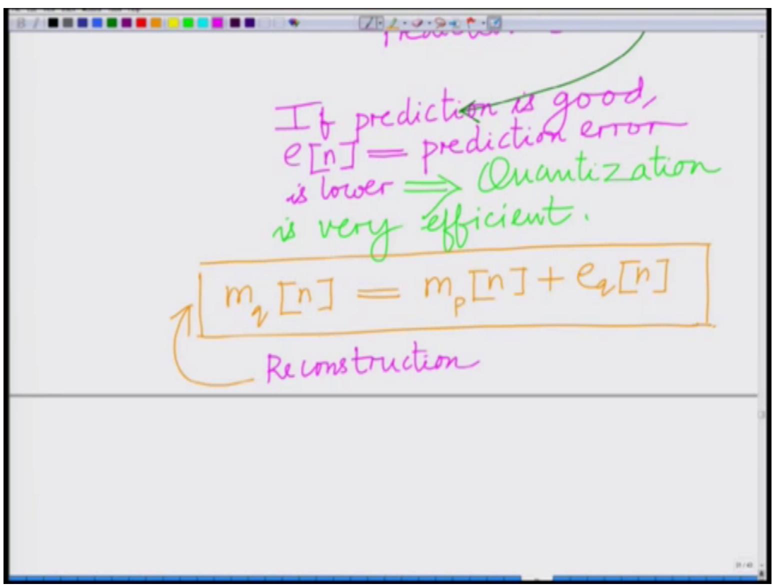
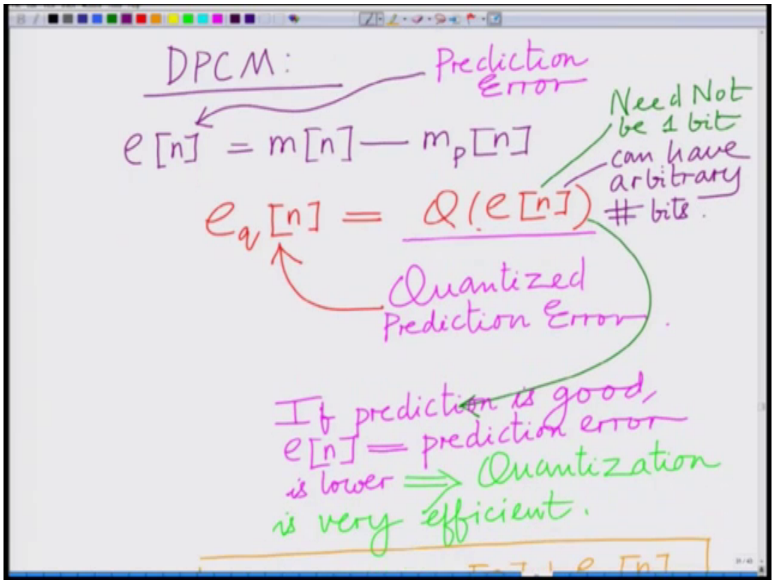
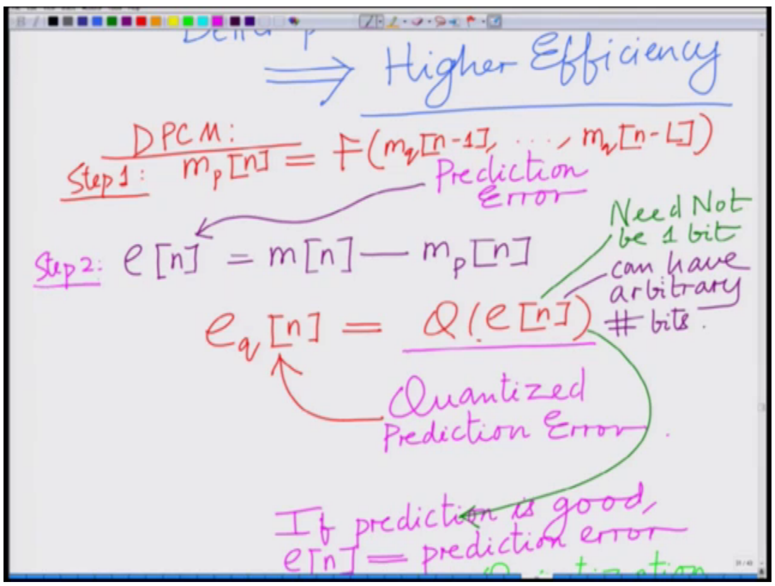
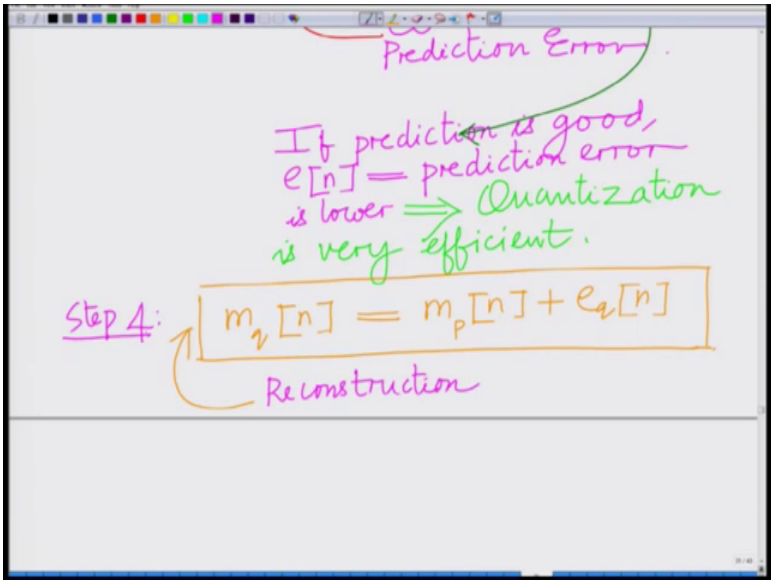



DPCM:
Prediction Error
e[n] = m[n] — m_p[n]
Need Not be 1 bit
can have arbitrary # bits.
e_q[n] = Q(e[n])
Quantized Prediction Error.
If prediction is good, e[n] = prediction error is lower ⟹ Quantization is very efficient.


⟹ Higher Efficiency
DPCM:
Step 1: m_p[n] = F(m_q[n-1], . . . , m_q[n-L])
Prediction Error
Step 2: e[n] = m[n] — m_p[n]
Need Not be 1 bit
can have arbitrary # bits.
e_q[n] = Q(e[n])
Quantized Prediction Error.
If prediction is good, e[n] = prediction error



Now, eq[n] is the quantized prediction error, now mq[n] the reconstructed error reconstructed signal is similar to delta modulation that is simply your well that is simply your mp[n] the prediction remember in DPCM this is simply mq[n minus 1] this is mp[n] plus eq[n], okay this is your reconstruction, okay this is your reconstruction, okay so this is the reconstruction this is in fact the identical thing that is going to be used at the this is your reconstruction, okay.

And now in addition one other thing that you have to observe this Q(e[n]) need not be need not be 1 bit, for instance delta modulation it is simply delta times sgn of (())(15:38) that is plus or minus delta. However in DPCM it can be an arbitrary number of bits, of course the larger the number of bits, the better the quantization, alright the better the reconstruction or better the quality, okay. So this Q can be of an arbitrary number of bits, okay can have arbitrary number of bits this Q can have this Q can have an arbitrary number of bits, okay.

And finally, the prediction mp[n] or rather you have your mp[n] or we can write this over here maybe you can write this over here you have your DPCM and your mp[n] the prediction equals F, where F is the prediction function mq[n minus 1] up to mq[n minus L], okay so this is the first step, this is the second step, okay where you are forming the prediction error this is the third step mq[n minus 1] equals mq, okay this is the third step eq of that is quantization error this is the third step and this is the fourth step that is reconstruction mq[n] equals mp[n] plus mq (ooh) mp[n] plus eq[n].

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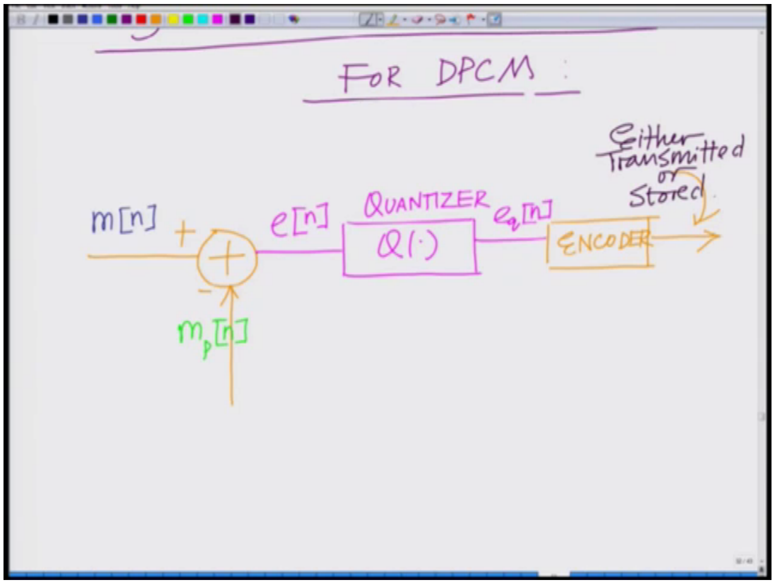

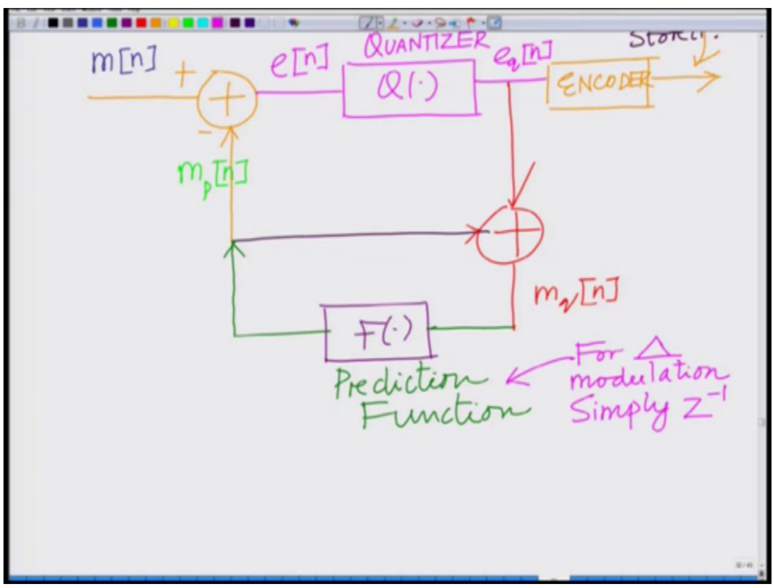

Now we can now a schematic diagram for this (())(17:39) for DPCM, okay this is a schematic diagram for differential pulse coded modulation, now we have your signal sample m[n] similar to delta modulation we take in the sample at every time instant n, okay now from this we subtract the prediction this is minus mp[n] that is the prediction, okay we subtract the prediction mp[n], okay that gives us e[n] which is quantized this is your quantizer to get the quantized error eq[n].

And now this quantized error as we know this is passed through the encoder to convert it into a bit stream this is passed to the encoder and this is either transmitted or stored the encoded bits stream is either transmitted or it is either transmitted or stored transmitted being transmitted over a channel this is a communication system transmitted over a channel or this is simply stored. Now this eq[n] as we already seen this is combined with the prediction mp[n], so mp[n] and eq[n] that gives rise to mq[n] that is a quantized sample.

Now this passes through a prediction filter or basically your F which is basically the prediction function, correct? So we pass this through the prediction function and the prediction function takes the past values L passed values so this is your prediction this is your prediction function, okay. So this is basically the schematic, okay so you have to pass it through the prediction function, okay. Now in the case of delta modulation this prediction function is simply zee inverse if you remember that simply delay that is mq[n] is delayed mq[n minus 1] (())(21:01) the prediction function.

So for delta modulation this is simple delay, for DPCM it can be constructed very efficiently taking also the statistical properties of the signal into consideration, okay so let us note that also for delta modulation this is simply zee inverse where zee inverse is the delay, okay that delay block single sample delay, okay.

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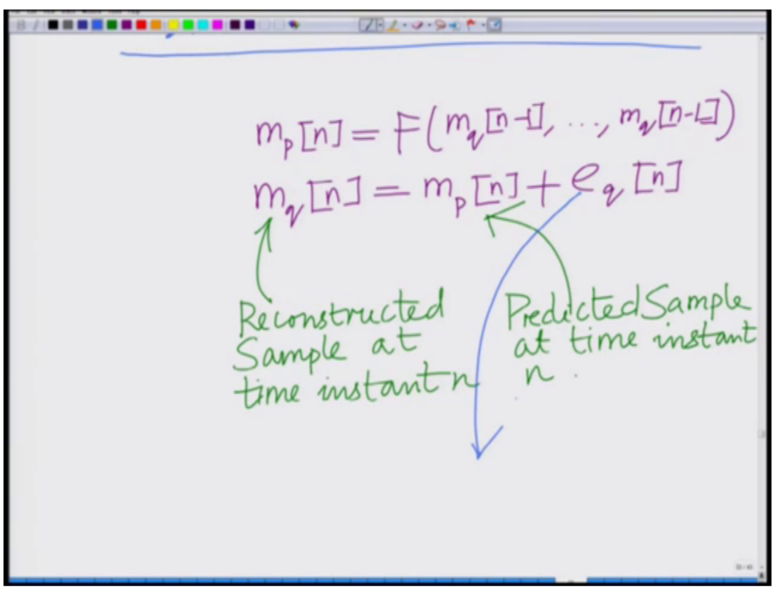

Now, let us now look at the reconstruction, let us now look at the reconstruction, now for reconstruction we already seen it is very simple reconstruction is you have your or reconstruction DPCM reconstruction or DPCM reconstruction you have well you have to first generate the prediction mp[n] is F(mq[n minus 1], up to mq[n minus L]) and then you have your mq[n] reconstructed value at time instant n is your mp[n] mp[n] plus eq[n], okay.

So this is quantized error at time instant, okay so let me describe this quantities mq[n] is reconstructed sample this is a reconstructed sample at time instant n this is the predicted sample at time instant n from the past L quantized sample predicted sample at predicted sample at time instant n and eq[n] eq[n] is the well quantized error at time instant n at quantized error at time instant n, okay so that is a very simple reconstruction we simply have to predict the sample mp[n] at time instant of n, mp[n] the predicted sample plus the quantized error eq[n] gives mq plus the quantized error eq[n] gives mq[n] that is a quantized sample or the reconstructed sample at time instant n, alright.

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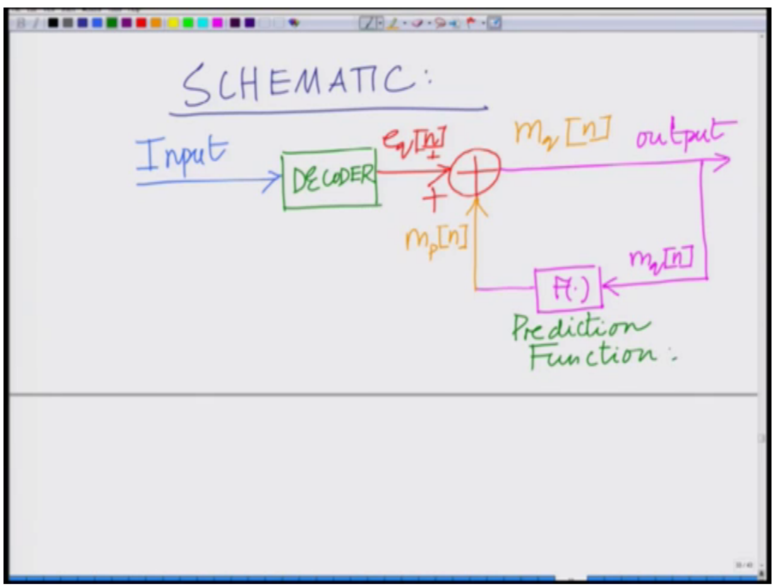

So let us draw a schematic for the reconstruction the schematic for the reconstruction will be very simple you have your input, okay from the channel or your storage device which is the encoded input you pass it through a decoder remember this is an encoded bit stream you pass it through the decoder, alright eq[n] is encoded to produce the bit stream encoded bit stream is passed through the decoder that gives us again eq[n] that is the quantized error to eq[n] you add mp[n].

So to eq[n] you add mp[n], okay that gives rise to our output mq of that gives rise to the output mq[n] now this output you also pass through the prediction filter again the same prediction function, okay you pass so this gives you your this is your prediction function you take in mq[n] L past samples of mq[n] and so this is your output so naturally this involves feedback as you can see so this is your prediction function you take the reconstructed output, take the past L samples pass it through the prediction function generate the prediction from the decoder you get the quantized error to the prediction add the decoded error decoded quantized error that is mp[n] plus eq[n] that gives rise to mq[n] which is the reconstructed sample at time instant n, alright.

So that is basically in summary differential predictive DPCM differential pulse coded modulation, alright it uses is a differential encoded scheme it is you can think of it as generalization of delta modulation in delta modulation we only use the reconstructed pass sample as the prediction and of course it is a single bit quantization DPCM generalizes that it generalizes by building a better function for the prediction which uses not just a single past samples, but L past samples and also the error that is m minus mp[n] that is the prediction error e[n] can be quantized using an arbitrary number of bits.

And DPCM is a very efficient prediction is a very efficient encoding scheme as I have already told you it is a pulse modulation scheme it can also be used for compression both for transmission and compression, it is a very efficient compression scheme and it is used in almost all of the modern audio video encoding standards for instance you can think of your jpeg, mpeg and so on, alright. So DPCM is a very efficient prediction technique or very efficient pulse coded modulation modulation technique coded modulation technique which is used for efficiently quantizing and compressing of transmitting the signal over a communication system, alright.

So it has a lot of relevance in modern storage as compression as well as communication application, alright. So we will stop this and we will continue with other aspects in the subsequent modules, thank you.