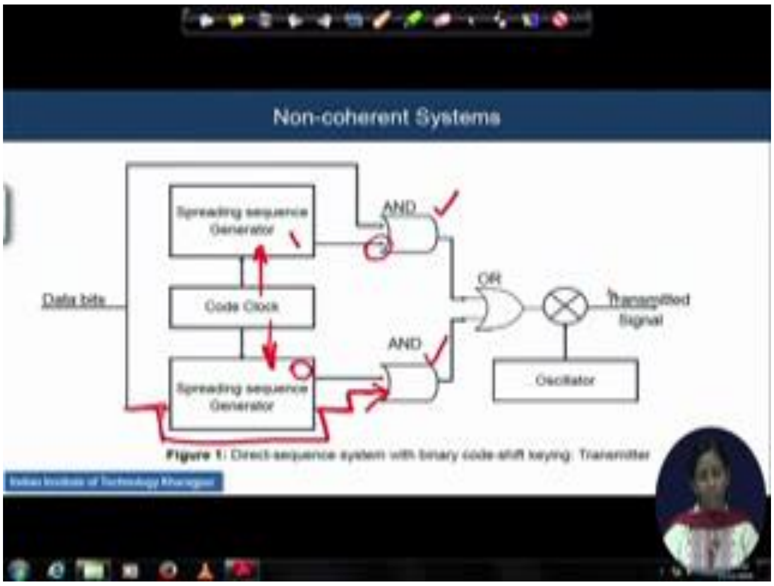
Spread Spectrum Communications and Jamming
Prof. Debarati Sen
G S Sanyal School of Telecommunications
Indian Institute of Technology, Kharagpur

Lecture - 22
Noncoherent Systems

Hello students. In this module we will discuss now the Noncoherent Systems. Basically target is to see that for noncoherent communications whether how do we despread the signal, and whether matched filter architecture that we have already discussed in the last module is equally applicable here, or we do we need actually to put some separate synchronization block here, to realize the system implementation. And if question is what will be the error probability at last of this noncoherent system using matched filter, in the receiver, such that actually there is a loss or there is non not a loss at all compared to the coherent communication systems. So, we need to understand all those points.

Question number one that we will be it will be clear is whether you can apply the matched filter structure alone without incorporating another synchronization block for code acquisition and code tracking for noncoherent systems or not. If the answer is yes, then with this structure with the matched filter structure what will be the error probability how it will be derived and what will be the expression for the error probability. Then the question is in terms of the when we are computing the error probability whether there is a loss involved are we losing in terms of some dB value in that SNR compared to the coherent communication system or not. If it is yes, then how much is it, let us start.

(Refer Slide Time: 02:05)



A noncoherent communication system the first figure is showing our typical block diagram of the transmitter of a noncoherent communication system. So, data bits are coming both in the upper and gate as well as in the lower and gate. And it will not be like this, it will be basically. It will be in order to going inside like this; it will be going like this. So, the data bits are coming this is not true. So, the data bits are coming like this. And spreading sequence generate, there are 2 different spreading sequence generators.

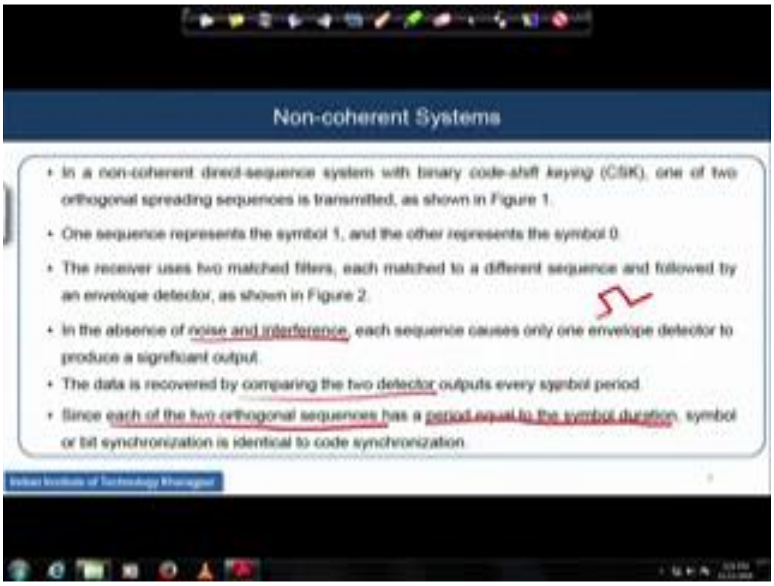
And the clock is triggering both of them, but depending upon the clock sequence actually either any one of them one of the sequence generator will be activated, and output of this sequence will be fed as an another input to the and gate. So, and gate is receiving the data bits and he is receiving the corresponding spreading sequences. So, remember as we have shown 2 difference spreading sequence blocks. So, one is sequence is dedicated for the symbol one another sequence is dedicated for the symbol 0.

That is why; already we know right that codes can be utilized for modulation also. So, here we are seeing that code is modulating the data bits. So, that is why it is a code shift keying. So, for each and every data symbols you are using different spreading sequences. And remember at a typical instant either module 1 so, based on which generator is actually activated for what kind of the data bits coming. Then either at a particular instant module number symbol 1 will go or otherwise symbol 0 will go.

So, either the and gate 1 will be high output will be high or and gate lower and gate will be high. The both the outputs are getting odd. They added in the or gate structure. So, once they are added here. So, any one of them are will be actually allowed to get transmitted. So, at a particular moment we understand by this structure that based on the choice of the codes and the based on the data stream that is coming. Actually, either upper sequence generator or the lower sequence generator is getting activated. And then actually so, each of the symbol is getting spread by the unique code unique codes, the code for the one and code for 0 are different.

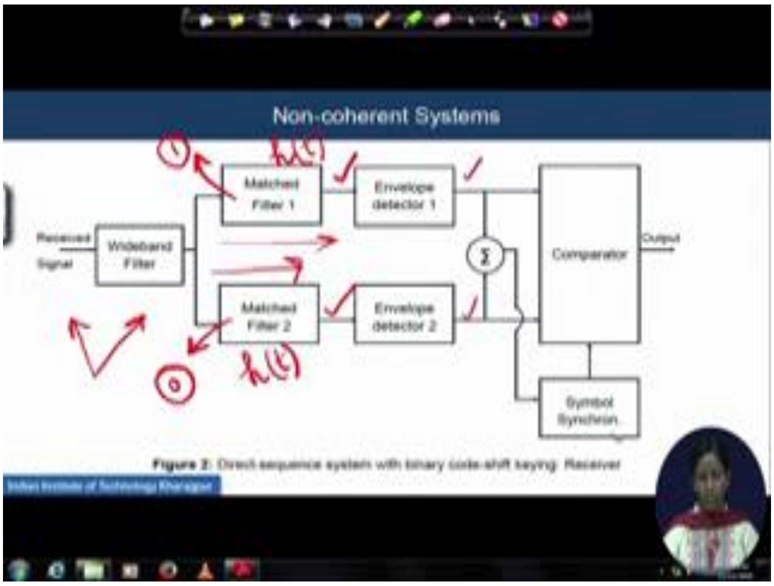
And at a typical symbol either the upper and gate output will be high or the lower and gate output will be high. And they are getting added inside the or gate and either at a particular instant t, either the symbol one is getting transmitted or symbol 0 is getting transmitted.

(Refer Slide Time: 05:28)



This is the structure of the transmitter. Let us see how the receive values looks like, the CSK so; I will give more information let with respect to the transmitted figure. Remember that in absence of this noise and the interference each sequence will cause only one envelope detector that actually in the figure 2, let us go and come back because otherwise it will be hard to understand some more points that is explained in this typical slide.

(Refer Slide Time: 06:00)



So, let us go for what and understand the receiver structure I will come back to the previous slide. See in the receiver I understood that the signal is transmitted at a particular time moment either I transmitted 1 or I transmitted 0 with the proper choice of their code associated with them. The received signal is received by the wideband filter, and that wideband filter output is now matched to the having it 2 different path in the receiver. So, the matched filter impulse response of the upper one and the merged filter response of the filter 2, they are not send actually they are basically matched to 2 different kind of the signal. One signal dedicated to say symbol 1 the upper one say dedicated to symbol 1 and another one is dedicated to symbol 0. So, each of them are matched to, we send 2 different sequences right from the transmitter for symbol 1 and symbol 0.

Here also we have designed 2 different matched filter matched to each of them. So, remember at a particular moment at the output of the wideband filter though it is fed to both of them, at a particular moment based on the signal with which actually the filter is matched to either the filter output 1 will be significant or filter output 2 will be significant. The output of this filter is fed to the envelope detector. This envelope detector is the way we have seen in the previous module that matched filter followed by an envelope detector is the best option to implement synchronization, without synchronization deceiver architecture, compared to only match filter and then picking up the peak of it.

We will understand also that that there will be a loss, but that loss is not that much significant at all. And it can be easily implementable also this architecture is easily implementable also. So, we henceforth we will go ahead with this matched filter with envelope detector output. And as we understand that compared to follow by the any one of the matched filter output high, any one of the envelope detector also will be high.

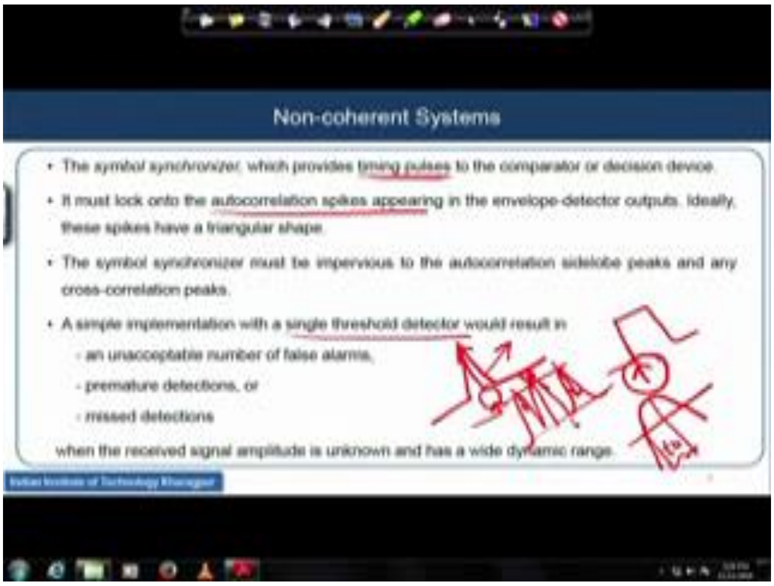
So, the summation of the both envelope detectors will give actually mean the output. And this sound nation summation will be actually the output of this 2 envelope detectors will be doing the will be also triggering the symbol synchronization and the comparator net network will be comparing both of them and synchronization will be coming into picture with 2 synchronize upper envelope detector signal, and then in the envelope detectors signal.

So, question is actually why we have done here actually added here the symbol synchronization. So, before coming there it will give any explanation let us go back little bit and the points that we left in the last slide let us finish it off. So, what we left here is that see if the noise and the interference they are absent. So, each and every sequence will every sequence for every sequence will cause only one envelope detector to produce the significant output that I have already told. And data will be recovered by comparing the 2 detector that also we have discussed seeing the architecture. And since each of the 2 orthogonal sequences who are also ortho this sequences are orthogonal to each other, they have a period equal exactly equal to the symbol duration. So, in the whole architecture of the noncoherent communication system, the synchronization basically means a symbol synchronization.

So, codes synchronization as well as symbol synchronization they are identical. So, you do the symbol synchronization automatically code synchronization will be coming to picture. Because you have utilized the orthogonal codes your data bits have basically modulating the orthogonal codes. 1 and 0 the data they are modulating 2 different orthogonal codes. So, the modulation is done at the rate of the symbol period. That is why the modulated symbol will be also having the period is equal to the symbol duration.

So, in the received signal after the matched filter output and the envelope detector, so if you try to do some synchronization left. So, that will be basically symbol synchronization. There is no meaning of telling it as a code synchronization. Even if you call it as a code synchronization they are synonymous, so with that actually for the remaining synchronization. So, the symbol synchronization block will take care of the fact and the comparator device is finally, going to compare both of the outputs envelope detector 1 and 2 and finally, giving a hard decision about which data bit was transmitted. Seeing actually from where actually the maximum output is coming. Based on that he will give the output of whether the decision of whether the message bit 1 was transmitted or message bit 0 was transmitted.

(Refer Slide Time: 11:33)



Now, the symbol synchronizer that we have seen in the last slide, this which provides the timing pulses. It is a symbol synchronizer. So, the start point of the timing where did the symbol start point is he will indicate. And to the comparator or the decision device and this synchronizer also should look the instant once actually it is detected then it will declare also that the perfect lock. And it should try to lock when the autocorrelation spikes are coming in the envelope detector outputs, and this spikes if you try to see in that the spike, that actually output of the envelope detectors are giving you that will be a shape of triangular and so, it may happen that actually it is depending upon the sharpness definitely actually.

You will be able to detect this movement or this instant very precisely. The symbol synchronizer must be impervious to the autocorrelation side lobe peaks and any cross correlation peak lobes. Because though we are expecting that something like that is expected, but remember it the shape of these auto correlation has we have learned, it heavily depends upon the kind of the code you are choosing. If it is a random binary sequence or m l sequence, it can you can expect actually that this kind of the triangular shape is expected to come at the output, and then you are choice of the locking because if the peak is sharp, your choice of locking or finding the perfect instant will be very easy.

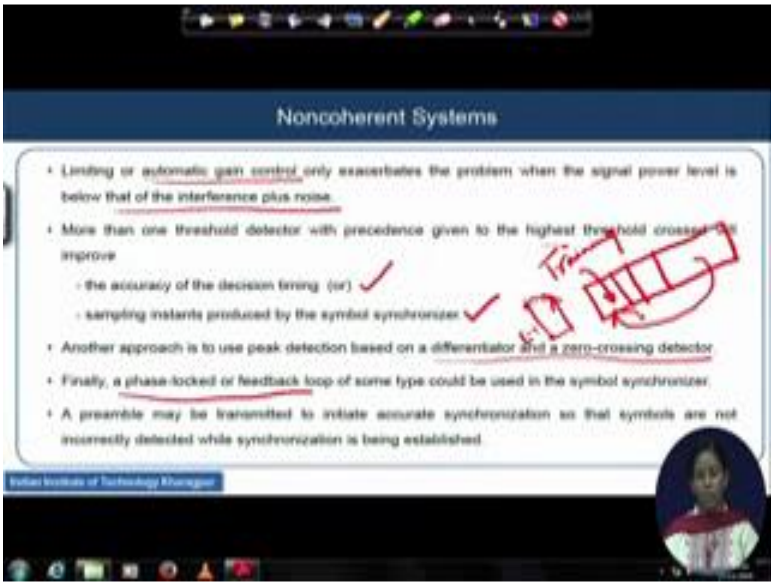
Think of a situation whether the when the peak is like this and the autocorrelation side lobe is also having very high peak compare to the main peak power. When the synchronization make it false locked, in the previously appearing one or if it misses the peak to detect it may declare that the lock is should be here. So, synchronizer the algorithm that you have been designing for the symbol synchronization it should be aware of the auto correlation pattern of the selected sequence and the algorithm should be such that should be precisely identifying the autocorrelation main lobe peak.

On the contrary if it is the cross correlation peak that he is define that he is defining on or he is relying on, in that situation also the side lobes of the cross correlation are playing a very important role, and comparable high peak in the cross correlation side lobes may give you actually the wrong detection points, synchronization algorithm should take care of that. So, algorithm should be device in such a way that most of the time you will be getting locked on the main lobes peak.

A very simple implementation that how will you do this symbol synchronization is a with a single threshold detector. And whenever the detector it put a threshold actually you know; what is the maximum side lobe powers, it put a threshold above there. So, whenever the power is accumulated power is crossing that it declares that there is a there is a peak. And, but if you are doing it with a very single detector kind of the easiest one, but if you do it with the single detector you may result in also some false alarms. Because see when if the curve is not very sharp and if is having some slope like this, if it is a main lobe is having some slope like this say, and this is a level of your detector single level detection threshold.

So, once actually the threshold is crossed, it will be synchronized will tell that this is there is a lock. Whereas, it is a round detection because your peak is actually having say t 0 apart from these initial one. So, sometimes it may give you some unacceptable numbers of the false alarms. Premature detection or it may also give you the missed detection to some extent. So, people prefer to have actually the multiple thresholds based to detection and when they received amplitude is unknown and has a very wide dynamic range also, in that situation basically depending upon one threshold detector is not at all a good suggestion to proceed with.

(Refer Slide Time: 16:16)



And there is a easy way to control that problem that we have discussed earlier. What we can do that, we can actually control the automatically gain control AGC, to reduce actually this is to resolve the problem, but only the problem is that when that is the below that, the whole staff actually the controlling the automatic gain control will automatically again may lead to you the false point lock when the signal power level will be below the interference plus the noise level.

So, the low value of interference plus the noise, the problem is also not good to resolve it by the controlling the automatic gain control power to gain control voltage. So, more than one threshold detector is a is a good choice and with given the highest threshold crossed will improve always that the accuracy of the decision timing the sampling instant produced by the symbol synchronizer. So, all those points the accuracy of the decision or timing or the sampling instants which are produced by the symbol synchronizer all of them both of them basically will be improved.

Another approach is to watch, is to use the peak detection based on the differentiator or the 0 crossing detector. Big detection algorithm can be also used on the differentiator as well as the 0 crossing detector based. Because without actually fixing only the single based threshold, only the single threshold. And actually trying to compare it what exactly is going another declaring the lock once immediately after crossing the first threshold level. Instead of doing that if you wish to detect only the peak then the there is a differentiator; that means, each and every moment you keep on changing keep on checking the sample value, in the current moment sample value peak as well as the previous moment sample value.

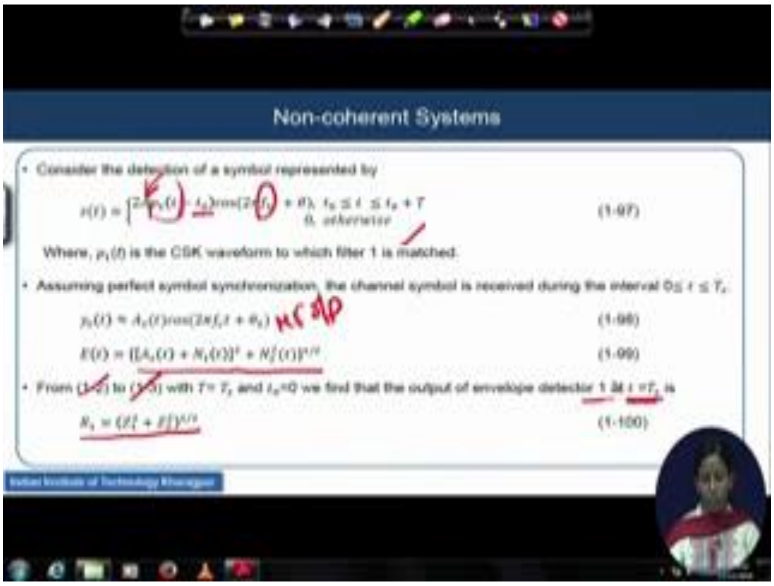
So, if you see actually that there is a continuous increment happening. So, you keep on going on before and before actually declaring the peak, and you do the declaration once actually there is difference is the instead of increasing little there is a decrease. Or sometimes we go ahead with a 0 crossing detector also, but finally, above all this is a phase locked loop or a feedback loop is a best option for the symbol synchronization. And whatever be the situation for the symbol synchronization we usually prefer to send training sequence inside the preamble of the data in the packet structure that we have earlier discussed if this is the packet and this is the preamble.

We will send actually some known training sequence inside that preamble to help the receiver in the synchronization process to establish, because in that situation the receiver will have the knowledge of the replica of the sequence that is expected to come. We call it a training based to synchronization. Sometimes we prefer not to, but this training based synchronization will give you high accuracy. The synchronization process, but is not spectrally efficient because this is a training data. This is not your useful data that you are transmitting. This is a training data that you are transmitting and this is the wastage of the bandwidth also in that sense. So, it is not spectral efficient, but it synchronization accuracy wise this is the best way to proceed.

Another way that we usually prefer is the blind estimate synchronization technique. Where we do not transmit anything like this from the transmitter, but what we try to do is seeing the pattern of the extracting the statistical I would try to extract the statistical probability of the received data symbols and try to device our synchronization process from the received data symbols itself, it extracts the estimate the it is try to extract that is estimate the timing estimation and timing information from the received data or received pay loads.

Another is data edate where actually the training sequence is send as well as the detected data output is fed inside the synchronization block, and then jointly actually this is the code synchronization when training based is going on and the data edate portion enhance further enhances the synchronization point, we call it a data directed or data aided, under the data supported by the data section it is the synchronization process another one is.

(Refer Slide Time: 21:21)

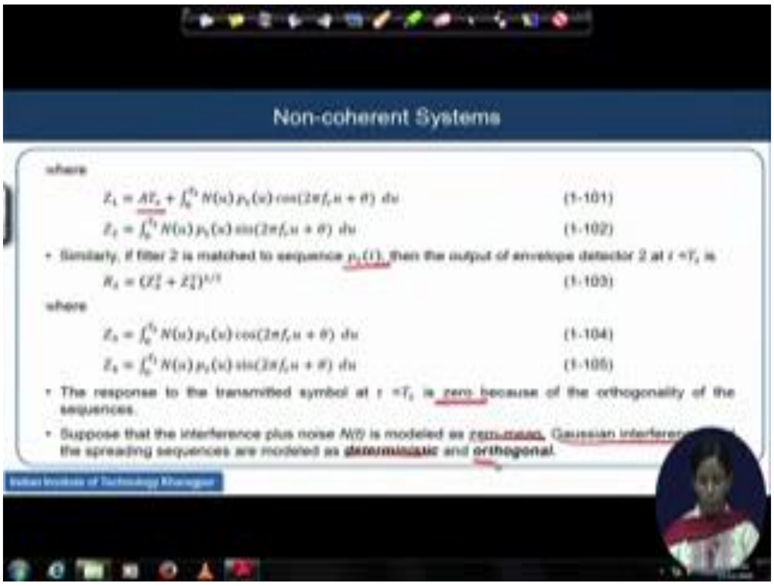


So, now consider the detection of a symbol which is represented by this expression. So, this is the received symbol that we have written here and we understand this format we have seen in the last expression in the last module also, p 1 t is the one period of the signal getting transmitted of the of the code sequence, t 0 is the delay, and f 1 t is the received frequency, signal frequency, and capital A we understand the polarity of the capital A will be governed by the data symbol itself. This is the period of our interest t 0 2 t 0 plus capital T and this p 1 t this is the CSK waveform to which my filter 1 in the receiver architecture please refer the receiver architecture block diagram once more, matched filter 1 it was actually on the upper part and filter 1 is matched with this p 1 t.

So, following actually the last expressions that we derived for the matched filter based despreading process, we understand that y s t can be approximated as a s t into cos 2 pi f c t plus theta 2. And the envelope detector output this is the matched filter output. This is the matched filter output, and envelope detector output also going by the expressions that we have derived in the last module. It will be ended up with a s t plus n 1 t square plus n 2 square t. And we also understand that in certain situation this n 2 t portion will be approximately deleted also. For certain situation and we also understand here that, with t capital T is equal to T s and t 0 is equal to 0. We find that the output of the envelope detector 1 at t is equal to T s this will be given by R 1 is equal to Z 1 square plus Z 2 square whole to the power half.

So, envelope detector just discards this 2 number, that envelope detector output or envelope detector at the point 1 that t is equal to T s is always given by the Z 1 square Z 2 square root of it, but what is this Z 1 and Z 2 we will explain in the later slide.

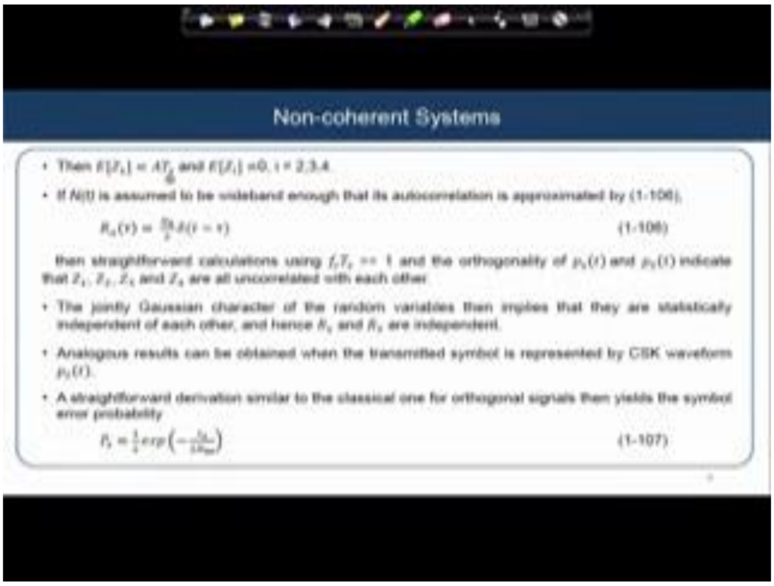
(Refer Slide Time: 24:10)



The Z 1 is nothing, but the intended signal section plus over the point of the interval, interested interval. It is the noise that is spread by the sequence as well as multiplied with the cos function of it. Z 2 is nothing, but that noise, but this is the contributed energy part, noise contributed to over and this is the orthogonal part noise on the orthogonal another orthogonal part. And similarly if my filter 2 is matched to the sequence p 2 t then again we will get the output of the envelope detector 2 is given by Z 2 square by Z 4 square and which having some similarity with the previous one, and Z 3 will be given by this expression whereas, my Z 4 will be coming out of this.

Say actually the response to the transmitted symbol at t is equal to T s will be typically 0, because of the orthogonality of the sequences. And suppose that the interference plus noise is modeled as a 0 mean and Gaussian interference and the spreading sequences are modeled as a deterministic and orthogonal.

(Refer Slide Time: 25:42)

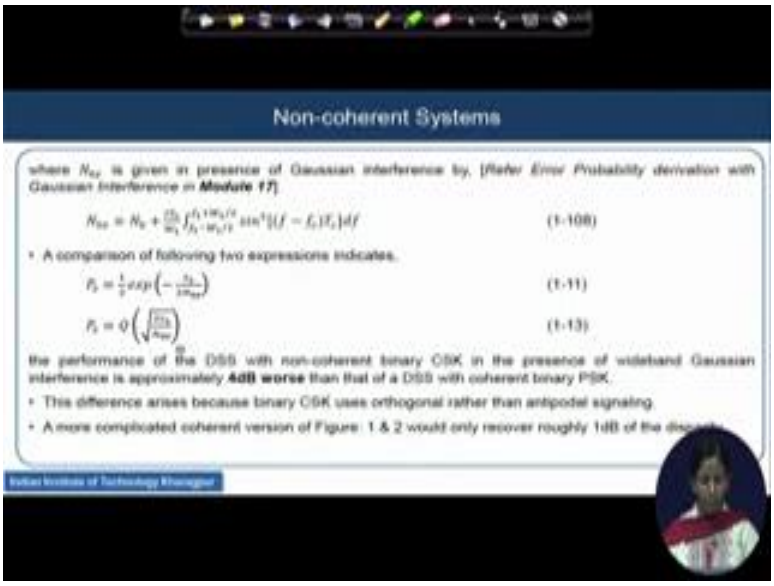


Then remember that expected value of this Z 1 e will be actually a T s. Because see comeback here this Z 1 is written by this. If I take the mean value of this Z 1 this is the noise section which is model as a 0 mean Gaussian random process. So, the mean of this whole expression will boil down to here. And Z 2 Z 3 Z 4 they are actually for i is equal to 2 3 4. For all that the expected value will be typically 0. So, if n t is assumed to be the wideband enough and it is autocorrelation function is approximated by this, we have seen it earlier also when we were declaring the first time we were discussing about the dss deceiver architecture. Then the straightforward some set what calculation here, which uses the f c into T s greater than equal to 1, orthogonal probability of p 1 2 and p 2 t, that we understand that all the noises that are getting added in the path number one as well as in the path number 2, and in the noise associated with Z 1 and Z 2 Z 3 Z 4 all are the other components of the noises.

All the noises are they are uncorrelated with each other. And the jointly Gaussian character of the random variables then implies that they are statistically independent of each other also. And hence R 1 and R 2 they are independent. So, if we can find that here and this guy. So, this 2 are now proved to be completely statistically independent to each other. So, similar results we can have with p 2 t where actually the discussion will be such that the Z 3 will be written as A T s plus this and Z 4 will be having this expression where Z 1 and Z 2 will have only the noise part. And similar outcome will be there also and we will be able to see that R 1 and R 2 are again becoming statistical independent considering that the noise samples are 0, means Gaussian distributed.

So, understanding both the path like such straight forward derivation is also probable possible for the error probability calculation which will be governed by this.

(Refer Slide Time: 28:17)

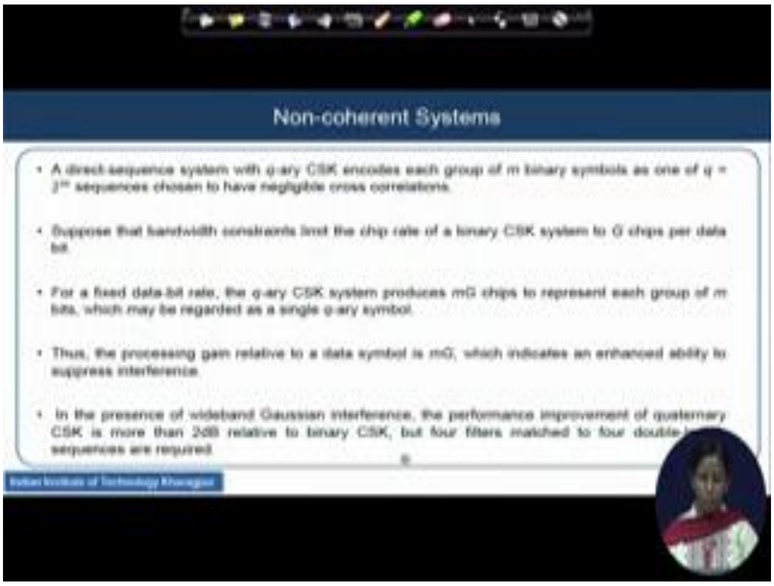


And this expression we have seen earlier, where your N oe will be given by the known expression that we have seen in the module 17 for the Gaussian interference is coming one.

And now you compare this 3 expression. Which 3 expressions? One expression is this one traditional one the noncoherent communication system. Another is the coherent communication system. A straight forward competition will show that a noncoherrent binary CSK system will have approximately of 4 dB worse will the performance will be approximately 4 dB worse compare to the direct sequence spread spectrum systems. So, what is the meaning of it is if you wish to get same error probability for your noncoherent CSK system you have to provide 4 dB extra transmit power to achieve the same error probability, same bit error rate, as compared to the coherent communication system. And this difference how does this difference arrive? This difference arrives from the fact that in the CSK we use orthogonal sequences; we do not use the antipodal sequences.

Usually, where the coherent communication system we use the coherent communication system, we use the antipodal sequences and antipodal orthogonal, not the orthogonal waveforms. It is antipodal signaling basically. Complicated little bit complicated version of both this transmitter receiver that we have discussed here, and that if we complicate it little bit more it is possible to show that this 4 dB loss can be improved little bit, but that also will increase the hardware intense some system design. And we can come up to a gap of approximately 1 dB; so from 4 dB to 1 dB. So, 3 dB compensation is approximately recovers roughly around one dB. So, 3 dB loss is not to be recovered around still 3 dB loss will be viewed.

(Refer Slide Time: 30:32)

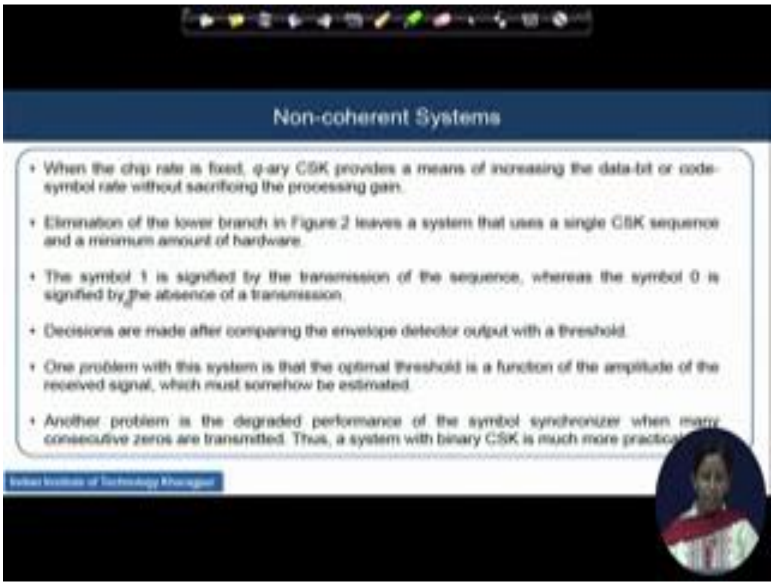


And now the another extension of this understanding with q-ary CSK encoders, that from each group of m binary symbols as one of the q equal to 2 to the power n sequences it will be chosen, and that sequence should have a very negligible cross correlation values for q-ary CSK transmission,

And suppose if there is a bandwidth constraint that limits the chip rate of this binary CSK system to say g number of chips per data bit then, for fixed data bit rate if your q CSK system produces small m into capital G number of the chips. So, you can think that each group of this m bits which may be regarded as a single q-ary symbol, which can be regarded as a single q-ary symbol. The processing gain relative to the data symbol will be m into G. And this indicates that there is an enhanced actually processing gain and it is says having an enhanced ability to suppress the interference also.

And we have seen that in the presence of our wideband Gaussian interference this performance improvement with your quaternary CSK system, I mean this is equivalent to our coherent q CSK actually the data rate wise. And it will have more than 2 dB requirement compared to the relative binary CSK system. And 4 filters matched to the 4 double length sequences I mean to see the structure the way it will be complicated definitely for the higher modulation schemes and 4 double length sequences should be required there when the chip rate is fixed.

(Refer Slide Time: 32:15)



So, q-ary CSK provides a means of increasing the data rate data bit or the code symbol rate, without sacrificing the processing gain. And if I now eliminate to this lower branch of this figure number 2. So, if I discard this total branch of this 2. So, it will give you the single carrier CSK system. And it can it can proceed actually of calculation of the error probability for this single ary CSK system. And in that situation your signal one will be transmitted with some signal and no transmission means it will be a symbol 0 getting transmitted.

The output of the envelope detector try to see what exactly is coming out, if it is close to the noise levels he declares that it a so, competitor declares that it is a 0 signal transmitted in that situation, and if it has some meaningful value and it is crossing some threshold also inside the competitor, the output of the envelope detector is crossing some threshold detector, then in the comparator will tell that the transmitted signal was 1, but one problem with this system is that the optimum threshold is a function of the amplitude of the received signal always and which somehow and that one this amplitude needs to be somehow estimated in lot of the situation.

Another problem was the will be that the degraded performance that we are seeing as comparison degraded performance will be also coming from the symbol synchronizer. When lot of the consecutive 0s will be transmitted, and thus system with your binary CSK is much practical in the sense that you are getting actually some situation or some star circuit architecture, where your some extra load for the coherent communication can be avoided, but at the same time the performance with close to the binary CSK can be obtained with the matched filter architecture definitely, and symbol synchronization some little bit we have to put our effort, because that is playing some vital role inside this.

And the gloss that is that we have seen actually compared to the conventional communication system will be around your 4 dB, that can be further reduced to by another 1 dB approximately, but below that even if you are trying to complicate the network, complicate the system further improvement on the b e r is further improvement on the SNR is not is not possible.