Spread Spectrum Communications and Jamming
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Lecture – 07
Slow and Fast Frequency Hopping

Hello students, in this model, we will learn today the detail about the fast and slow frequency hopping. Mainly with taking two examples - one on the fast frequency hopping, one on the slow frequency hopping.

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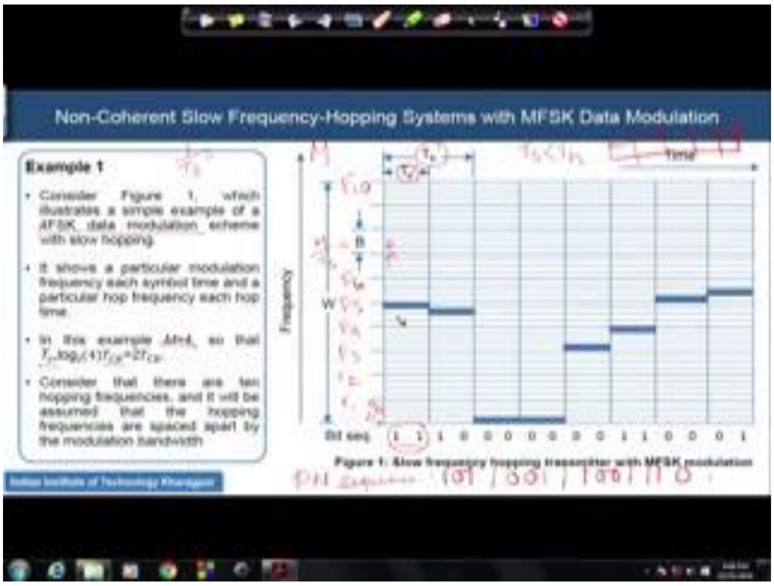

We will start today with non coherence slow frequency hopping system with MFSK data modulation. In the last module we have already discussed about the M array FSK data modulation scheme which will be the basic data modulation for today's concept resistant consideration both for the slow frequency hopping as well as for the fast frequency hopping. In our example; we have considered a 4 FSK data modulation scheme. It means that, for a we have a M array toned and data can be transmitted selecting any one of the M tones and then transmitting over the array. 4 FSK data modulation scheme, we will allow you to choose four different carrier frequencies, from a set of M, capital M is equal to 4. Any one of those four carrier frequency will be able to choose for your data modulation.

We are considering this figure one, where actually any one of those four FSK modulation that you are choosing is shown by this four smaller groups in each and every hopping portion. This we have considered here that, the bit stream that are entering for modulation they are having the bit duration is equal to T into TCV. Hence, the symbol duration we are having here if I consider M is equal to 4 then we are having the bit duration, symbol duration T s is equal to twice of C B. It means what? It means that actually we are having within a symbol 2 bits and these 2 bits are actually selecting the frequency tone.

For example, for 1 1 our selected frequency tone will be small f 4, for your 1 0 it will be f 3, and hence, it will be F 2 and F 1 for the remaining 2. Another consideration is that, the consideration of time, symbol time as well as the hopping time. The symbol time here will be considered as T s, whereas the hopping time will be considered as the T h. There is a nice relation to consider to be a slow frequency hopping system which is like this; if your symbol duration is less than the hopping time duration, I mean the T s is less than the T h and not only that T h is having a integer multiple of T s, capital N into T s is equal to T h something like that then only you can consider that there is a slow frequency hopping going on. I mean within a hopping time you have multiple number of the symbols getting transmitted.

Another consideration here is to understand what is the modulation bandwidth? Capital B here is the modulation bandwidth. Modulation bandwidth consideration will come from the consideration of this T s. This T s is my symbol duration. So, the 1 by T s will give me the duration of this frequency, of this modulation frequency or toned frequency, this is 1 by T s and hence, as we are having four in such kind of the tones. So, your B will be is equal to 4 into 1 by T s in our case basically, it is M by T s will be giving you the duration of the modulation bandwidth.

There is another understanding if I am having modulation bandwidth is equal to B and then what is the total spreading bandwidth? I am having a several hopping frequencies available in my hand, last module, I explained than in the case of the frequency hopping we have a wide bandwidth W which we divide over the multiple channels. This channels here I have shown by this. So, this is capital F 1, capital F 2 the hopping frequencies over the whole bandwidth W I have divided the total available bandwidth over such and such channels F 1, F 2, F 3, F 4 like that. So, count here, we are having from F 1 to F 10 different channels.

So, the situation is such that I am having a bit stream coming into, the coming into and then based on the bit pattern, I am constituting the symbol considering 2 bit, and that symbol is choosing the MFSK tone and each MFSK tone is getting hopped over a selected frequency, over a selected channel, which channel will be selected while G A which will be selected from the F and that channel will be selected definitely by a set of the P N sequence.

So, for example, in my case the hopping is such that the sequence is something like this F 1, F 2 let me complete this F 3, F 4, this is F 5, this is F 6. So, my P N sequence has generated such a way that it has selected fast F5. So, sequence was; obviously, 1 0 1 and then the sequence was F 1, so, it should be actually that 0 1 then it is going to F 4, so, it will be 1 0 0 and then again it is going to F 6, so, it is 1 1 1 0. So, the sequence, there is a sequence frequency synthesizer, who is continuously generating the sequence and based on their access generated sequence, the transmitted tone is getting hopped over.

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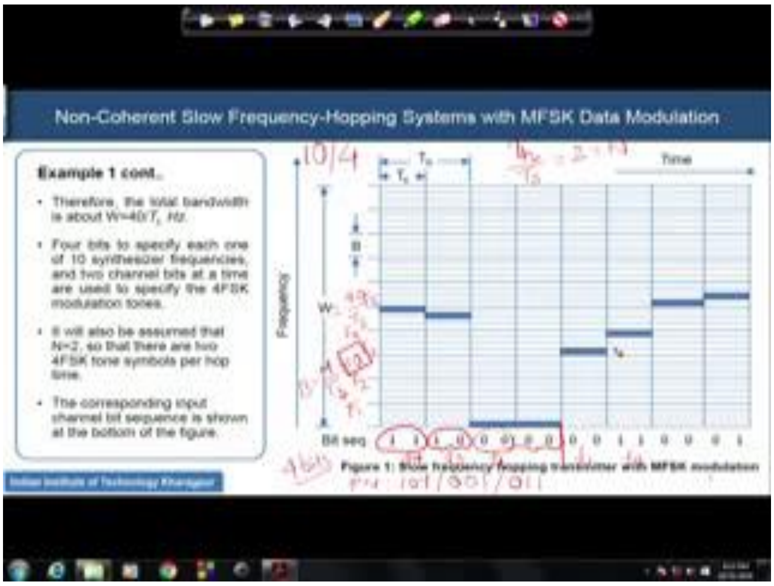

We are continuing in this slide, the discussion of the previous one. So, as we have understood that the whole bandwidth will be the multiplication of your B, what is about bandwidth of the modulation bandwidth multiplied by number of such stages you are having. So, finally, this W in our case as we are having 10 number of the different channel to hop, and per channel we are having 1 different frequencies to choose, hence, the total bandwidth capital W will be is equal to 40 divided by T s. How did it arrive? It is something like this; we understand that B is equal to our M by T s and such M by T s, the such B, how many B's we are having here is equal to 10. So, it is 10 into 2 M by T s. So, hence we are ending up with 40 by T s, is the total bandwidth.

Remember, in order to generate the 10 different frequency hop channel, in order to identify that you need actually 4 bit, for one of the is 10 synthesizer frequencies generate any one of the synthesizer frequency you need at least 4 bits, to generate it. So, there is one set of the bits. Who is telling you how to generate and what is the specification of the generation for this frequency hopping synthesizer frequencies. Another is the bit sequence that you wished to transmit who is actually modulating the carrier by MFSK. In our case to understand the situation we have considered, that within the hopping duration the symbol duration is chosen such a way that T h by T s is equal to 2. This is our capital N that means, we can transmit two MFSK symbols within the hopping duration.

So, let us understand now the bit sequence is coming like this 1 1 1 0 0 0 0 0 0 0 1 1 1 0 and 0 1. So, the first symbol is 1 1. So, hence, it should choose small f 4 it is the MFSK tone that he is choosing is the highest tone MFSK equal to 4 and then he is trying to choose the hopping bandwidth and hopping frequency, sorry the hopping frequency will be governed by the incoming bit pattern. So, incoming pattern that we have seen earlier the bit pattern should be such that it was F 1, it was F 2, this was F 3, F 4. So, we are if first in the channel number 5. So, P N has first generated 1 0 1. We have chosen the channel number 5 and our MFSK tone was 4, hence the transmission should go like this.

Our next bit 1 0, hence the symbol is 1 0. So, he will choose the carrier MFSK tone number 3 which is equal to my F 3 and at that moment P N sequence should not there is a change in the hopping because within the hopped duration like this within 1 hopped duration, we are allowed to send 2 symbols. So, hence with the same channel P N sequence is not changing its frequency and it is not generating an another half frequency hence, the second symbol is also getting transmitted in the same channel F 5, but only thing is that based on the data the modulating tone it is has got changed.

Now, after 2 symbol duration in the third slot when the bit pattern has changed to 0 0, so the symbol is actually 0 0 choosing the MFSK tone 1 which is the lowest tone and at this moment the P N sequence has given generated the synthesizer frequency is equal to 0 0 1. So, you are choosing channel number 1 and transmitting with the MFSK tone 1. The next bit pattern is again 0 0. So, again you are transmitting the with tone number 1 only. Like that if you proceed if you will be able to see that for corresponding for these 2 tones the tone frequency synthesizer frequency has not changed to the channel has not changed here the channel is changed. So, P N sequence has generated the equivalent number 0 1 1 which is choosing the channel number 3 and based on the bit pattern once you are at frequency MFSK tone number 1 and here you are in the MFSK tone number 4. So, without changing the channel you are basically changing the tone you have chosen.

So, with these understanding, this is the way the MFSK slow frequency hopping system data is generated.

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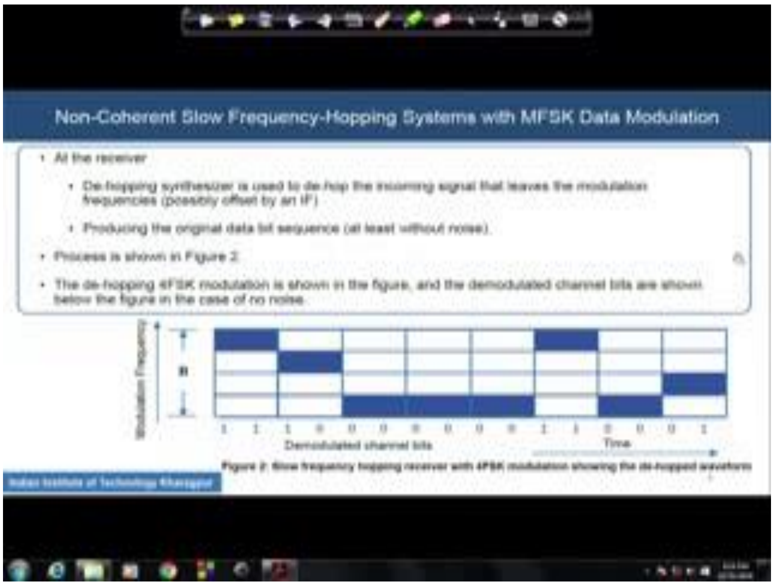

And we will quickly have a look into the receiver, where actually we will change the receiver, pattern will help us to de-hop the signal for de synthesize, the signal and we will be able to retrieve our own data weight. So, this is the typical task getting performed in the receiver. In the receiver de-hopping synthesizer, we use to de-hop the incoming signal that first leaves the modulation frequencies. For example, we were hopping over F 1 to F 2 to F 3 say. So, that hopping will be turned off. So, that is the meaning of de-hopping and they will produce the original data bits sequences, if we are considering that we do not have any noise in the system, then the de-hoping and demodulated channel bits will look like this. See after the, this is the modulation bandwidth. We saw in the earlier slide, we saw in the earlier slide, that first we have transmitted; we have transmitted over the channel. So, now, the channel the hopping over the channel concept is over because it was de-hopped.

So, now we will concentrate only on the MFSK tones we are left with once the hopping pattern is turned off. So, first we had the highest F 4, the frequency tone F 4, then we are having the frequency tone F 3, then we are having the frequency tone F 0, simultaneously, for two symbol period. So, like that here in the receiver we are getting it back. First with the tone number F 1. First we write in the tone number say F 4, then we were in the tone number F 3, then we were in the tone number F 1, it is not 0 it is F 1. So, we were in the tone number 4, then we were in the tone number 3, and then we were in the tone number 1, and like that actually we are ending up with the different MFSK modulated received signal and easily actually we can get the our demodulated data back, because we understand that actually the highest frequency MFSK tone corresponds to the data symbols 1 1.

So, this is the simplest way to understand the 4 FSK modulation scheme and we can actually change some modulation from 4 FSK to 8 to 16 and to 32 to complicate the system move and also we can change the hopping channel, available channel bandwidth. You can divide the available bandwidth over from 2 to 4 to 8 to 10 to 16 anything we wish.

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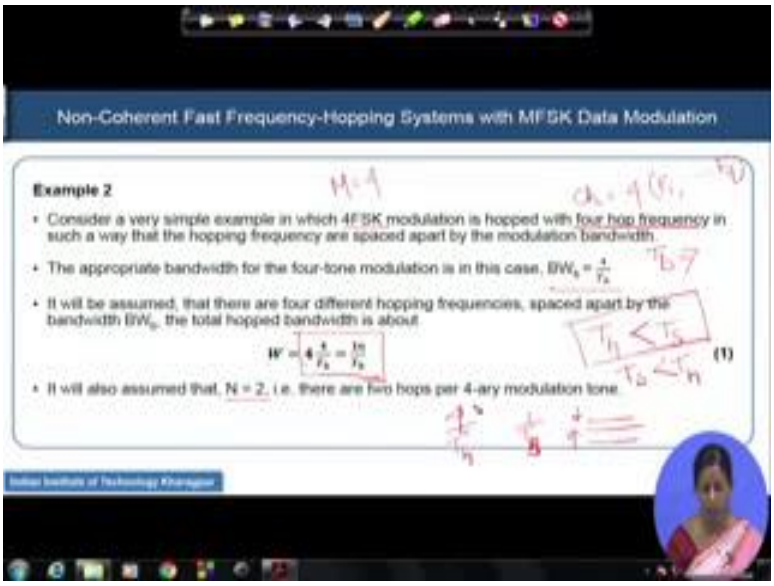

Example 2; now, we will talk about the fast frequency hopping system with the help of example on we will start with once again to make the understanding clear. Remember, again we are starting with a 4 FSK modulation scheme and remember we are having of 4 hop frequencies. So, my channel this is equal to my channel my channel I having 4 one F 1, F 2, F 3 and F 4 which corresponds to our understanding F 1 to F 4, like the earlier slide and here, 4 FSK modulation scheme means M value is equal to 4, I can choose any one of this frequency tones for my transmission.

But remember it is a fast frequency hopping, so the way we will be hopping is with the way we will be hopping is something like this for each and every is transmitted signal, for each and every transmitted bit, the hopping will be going on. The thing when we will define a hopping to be a fast is or slow is something like this; it is relative to the available hopping duration. If your symbol duration is actually greater than the hopping duration; that means, for within a symbol duration there is a change in the channel you are hopping from one frequency to the next, then this is the really fast hopping and if it vice versa, I mean the symbol duration is small compared to the hopping duration what we saw in the last slide then is slow frequency hopping.

Here, we will see the effect like this. That how actually, when the symbol duration is larger than the hopping duration, how the hopping is going on. The appropriate bandwidth for this 4 toned modulation can be written as B WB is equal to 4 by T s. So, what is this? 1 by T h we saw actually earlier, that is the separation between two carrier MFSK tones that we have selected. So, this is equal to 1 by T h, this was sorry earlier it was 1 by T s, this time actually, it will be governed by because T h is the lowest time possible duration in our situation. So, here it will be 1 by H and we have such 4 different tones choice. So, it will be 4 by T h in our situation in our case and the tensor total bandwidth how will we go ahead with we have 4 such channels. So, total bandwidth will be 4 into 4 by T h which is 16 by T h finally, and we will consider that N is equal to 2 like the earlier case which means what, which has which means that we have 2 hops so for 4 array modulation tones. I mean this will be the point will be cleared in the next slide, immediately we will go.

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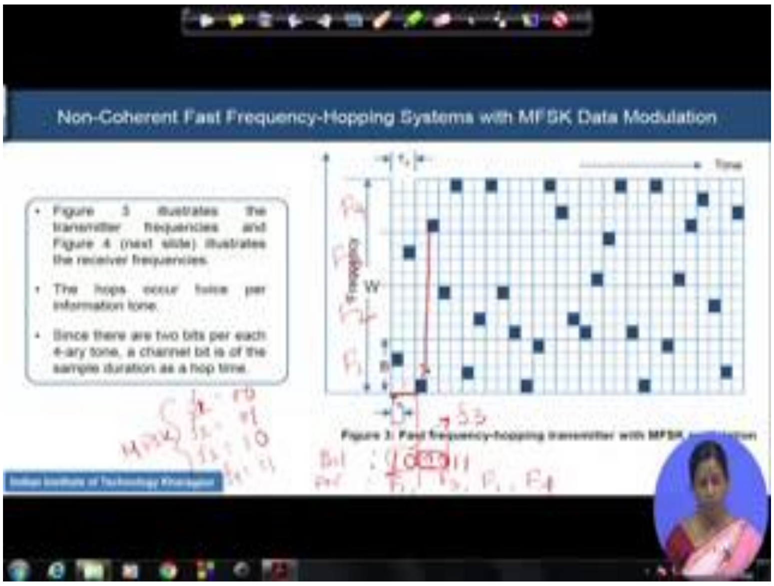

So, this is the situation, what we were trying to explain in the earlier one. See this is the hopping time and this is my symbol time. So, what is happening is within one symbol duration you are hopping twice, and this is the bandwidth of our understanding and this is the total available spread bandwidth, that the expression, corresponding expression was given in the earlier slide, and here time axis as usual in the, it is one the X axis wise the frequency, hopping transmitter is the again we are in the MFSK modulation tone. So, the choice will be something like this here with the way, the thing is coming is eventually, we were, we have transmitted the bit stream like this - bit stream came as 1 0 then 0 0 then it came 1 1.

So, let us first understand for this 1 0 came for the first T s duration, 1 0 within that we are having 2 bits and then we have to hop also twice. So, it is by default coming like this for each and every bit you are hopping and let us understand that how the P N sequence is coming up. The P N sequence came like this, out of the 4 hopping you choose the frequency channel number 1 first, and then you go to channel number 3, and then you come to channel number 1 once again, then go to channel number 4. So, P N sequence is generating like 0 0 1 0 1 1 0 0 1 0 1 0 0 like that, continuously it came. So, what will happen? When the first bit came, I should be in channel number 1, but what is the choice of this tone, the choice of the tone will be given by combinedly by this 1 0, the whole, the total symbol. So, 1 0 is equivalently to the choice of the tone number 3.

So, I am considering that 0 0 corresponds to tone number 1, 0 1 is corresponding tone number 2, 1 0 is corresponding to tone number 3. So, I am considering like this when 0 0 will come the tone number 1 will be selected, when 0 1 will be coming tone number two will be selected, when 1 0 will be coming tone number 3 will be selected, and 1 1 1 tone number 4 will be selected. These all tones are the MFSK tones.

So, first 1 0 came. So, I chose the tone number 3, but within tone number 3, I have to hop from where to where? I have to hop from channel number 1 to channel number 3. So, what I did? For 1 bit and there are 2 hops. So, for 1 bit I can view in 1 channel. So, I have gone to the tone number 3, but channel number 1, this is my channel number 1, this is my channel number 2, channel number 3, channel number 4. So, see for the first bit the tone was actually 3, tone number was 3, but channel was 1, when the second bit came tone was 3, but channel became suddenly 3. So, channel we have changed to 3.

Next bit was 0, but for 0 0, we understand that we have to select the MFSK tone 1. So, we selected tone 1 and we try, see where the channel is channel was F 1. So, we were here and when the channel, the bit came to the fourth one then it was against 0; that means, the same channel same tone will be there, but the channel suddenly changed to 4. So, for the same tone, keep the same tone, just change the channel. So, channel got changed from here to here, but see tone has not changed, because tone was selected by the combination of this pair. So, this is the way we do it, is very hard actually if we do any change hopping within 1 bit duration. Then to track the sometimes we do it also, but in order to track the system in a such a situation we will be really tough and those systems are very really very fast kind of the hopping system .

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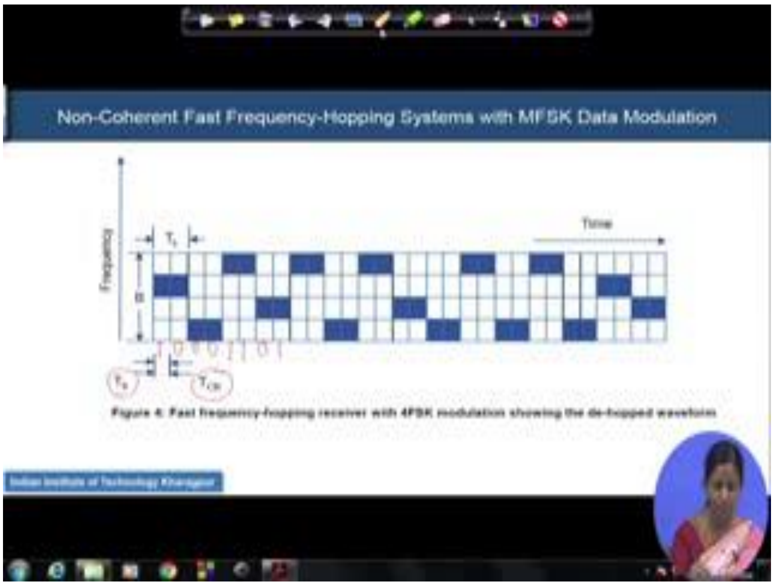

Next, there will be a non coherent, fast frequency hopping systems, with MFSK data modulation in the receiver side. In the receiver side, we will be de demodulating it see this is the frequency axis and this is the time and we have having the bit duration as well as the, which is equivalent to my T CB also. As we have understood that our bit duration will be is equal to T CB, the incoming bit duration will be is equal to the T B will be is equal to the T CB. If there is no coding involved and as we understood that once you remove the hopping, it is dehopped, then automatically you will be ending up with this kind of the situation, you will be all the bits who were actually in the separate channel they will come down and side by side they will fall like this.

So, the way we will be ending up with coming here actually, the bit that we will select it is the third frequency so; obviously, we will select that decoded bit is equal to 1 0, here the decoded bit will be 0 0, here the decoded bit will be equal to 1 1, here I am ending up with 0 1 like that, automatically will come up.

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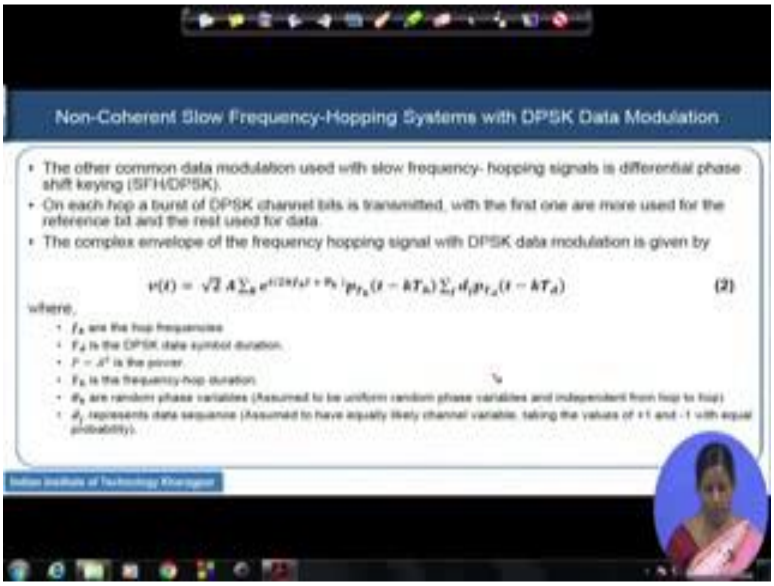

So, if we go and look into the non coherent slow frequency hopping system, the typical mathematical equations, so we will be seeing that. This is, A is the amplitude of the signal that you are transmitting. Hence, the power will be a square F K is the hopping frequency that you are transmitting if we consider that DPSK data modulation scheme, then T D is duration of that data symbol. DPSK is a very common and very preferable modulation scheme for this slow frequency hopping schemes and T h is the hopping duration as we have seen. So, V T will be the signal model where actually this is the portion, where you are DPSK modulation is going on, this is the frequency hopping section and this is the (Refer Time: 26:30) associated with that hopping getting considered.

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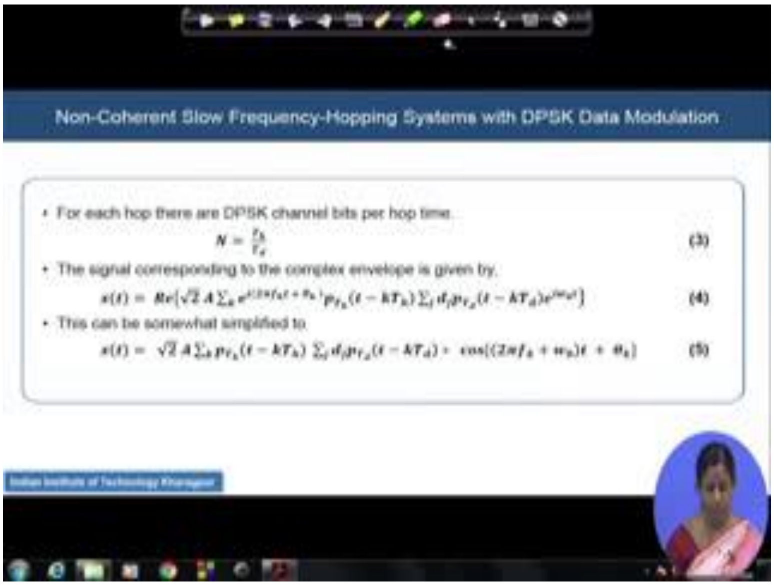

So, for each and every hop, we understood that, there will be the number of the DPSK channel bits. Those channel bits here, will be considered as T h by T D, because T h is the hopping duration and this is my DPSK symbol duration. So, division of that will give me definitely the channel bits per hop, I am transmitting. From the equation number 2 if we take only the way the signal is getting transmitted it will simply the complex envelop of that V T which is nothing, but like the last module we have seen that it will be real plus for real part of that whole transmitted signal of the equation 2, which can be further simplified by replacing this E to the power I J term as cos plus sin and we will be ending up with the equation 5. This is the simplified form of the signal that is the DPSK data modulated slow frequency hop signal that is over there.

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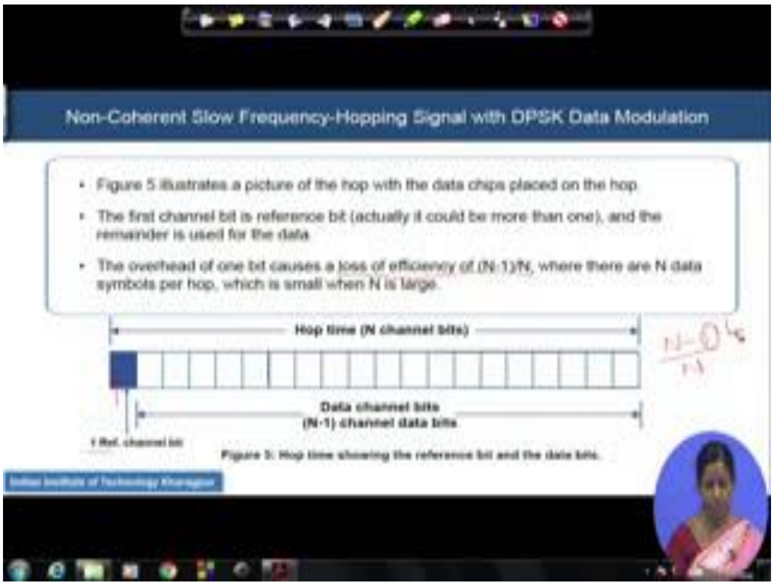

So, this is the figure that illustrates how we pack the signal before transmitting. So, these are the all the DPSK data bits, that will be transmitted and remember for DSSS system, synchronization is a very typical issue, for that we usually sent 1 or 2 reference channel bits, to identify to estimate the frequency or change the timing set in the DSSS system, and then we try to relying the risk part of the frame bits, so that we can really extract our data.

Remember, actually once we are adding the difference channel, which is does not mean that we have to add always a single reference channel bit we can have a multiple bits also added here and once we are adding that channel bits hence, given this frame you are losing some part of the frame, to transmit the reference channels. So, the terms of the efficiency we are losing somewhere. So, there is a loss of efficiency associated in the transmission and how many number of the bits you are adding, there based on that your references is calculated, as here it is 1. So, N minus 1 by is the loss of efficiency if you increase this number from 1 to some higher. So, let us, it is L. So, basically the loss of efficiency will be given by N minus l by capital N.

So, in some like that some BPSK system, we can have also go ahead with the BPSK kind of the data modulation also. The complex envelop of the frequency hopping signal with BPSK data modulations looks similar, that of a similar DPSK 1 where actually instead of my modulation time defined by the modulation time, defined by the DPSK we will be defining it by DPSK. The rest of the part looks similar, where this phase phi K information is this S K associated with the random phase that we have seen in the last module. This is the random phase associated with the generation process itself and it is independently actually from hop to hop.

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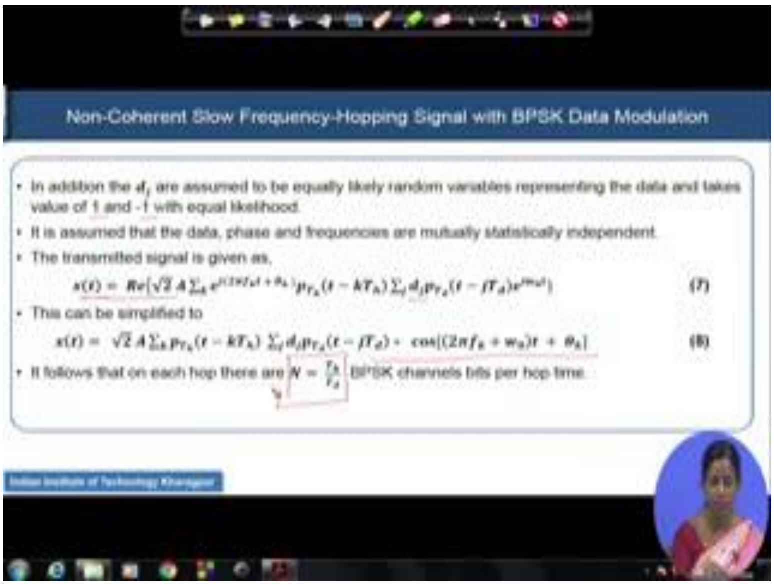

Similar to the earlier one, that D J, that we have added here, like the DPSK, here also this D J are equally, equal likely the random variables and they are having plus 1 or minus 1 equally likelihood values. And remember this X T can be re constant can be formed similar, with the similar logic that we have followed in the last class and then by expanding the exponential term we will be ending up with the simplified form of the BPSK data modulation, based slow frequency hop signal. Here, like the DPSK case we will be having the number of the channel bits, per hop time given by T h by T D.

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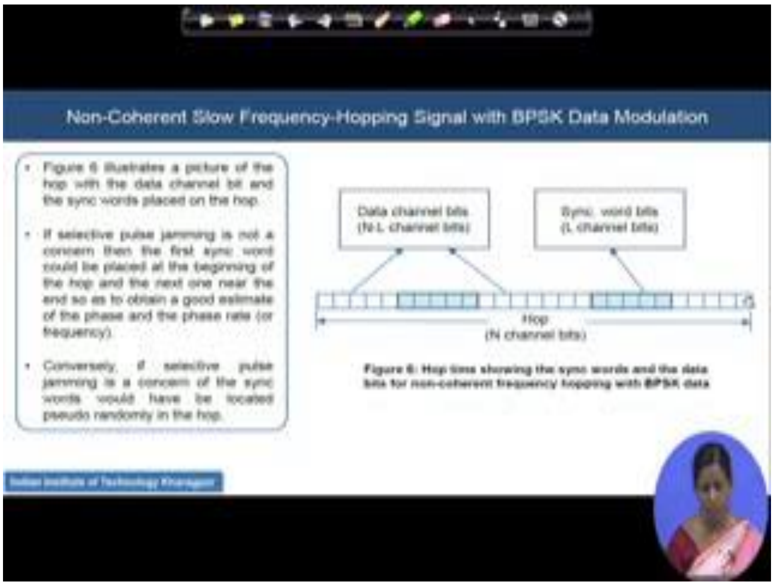

This is actually the BPSK data modulation expanding, getting explained in terms of a figure, where this is the total number of the channel bits, we are planning to transmit; we are planning transmit and here, if we are thinking that there is not a selective jamming going on and then actually the all the synchronization bits, we usually prefer to transmit at the beginning, but if that is a chance that actually there is a selective jamming going on, then we prefer to distribute the synchronization bits or the channels like this here we have distributed into two different classes of the whole data stream, that is going on.

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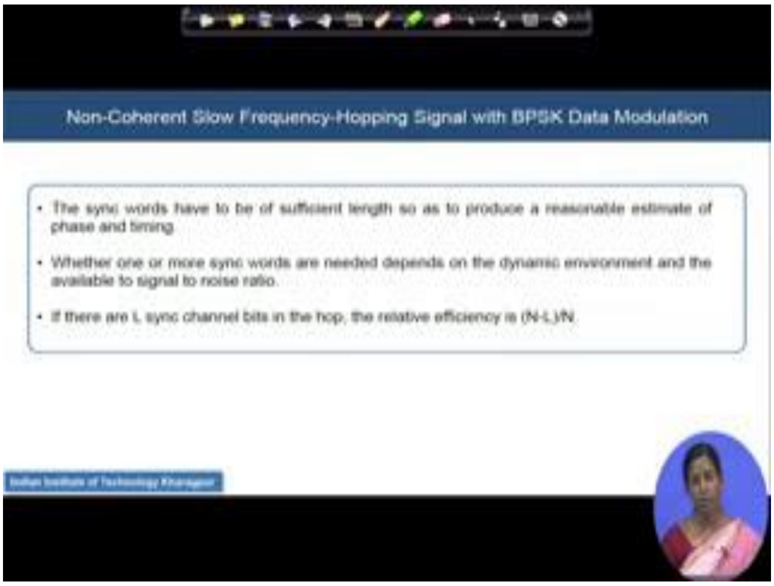

So, this thing was fundamentally can be very sufficiently large to produce a reasonable estimate of the phase and timing, but it heavily depends upon the condition of the channel, condition of the jamming situation, and based on which we design the sync words, which is not having any typical confirmed length issues. It is heavily dependent on the dynamic environment, and also whenever you, but please remember, whenever you are increasing the length of the sequence then definitely your efficiency is decreasing and it will be decreased by a factor this capital of L that is shown here.

In the next module, we will have a discussion on the remaining part of the two different, remaining two part of type of the spread spectrum communication system, what is the time hopping as well as the hybrid.