Advanced 3G and 4G Wireless Communication
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Lecture - 31
OFDM Example (Contd.) and Introduction to MIMO-OFDM

Hello, welcome to another lecture in the course on 3G, 4G Wireless Communication systems.

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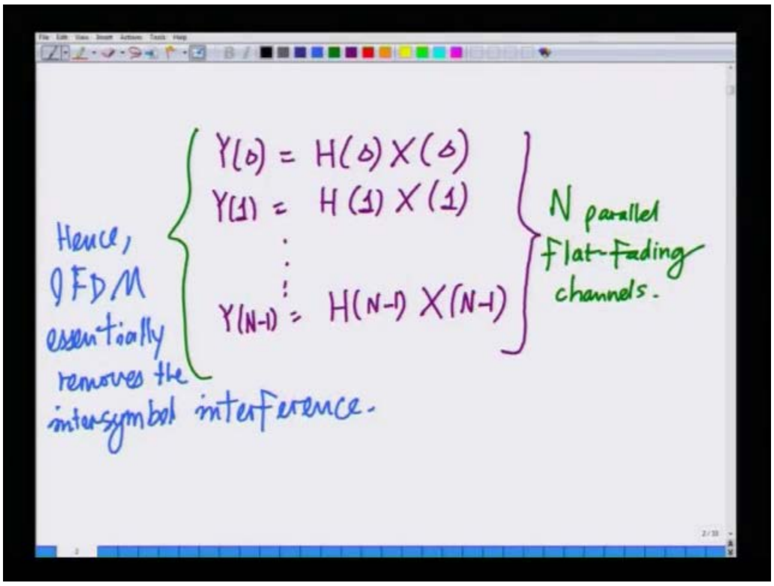

In the last lecture, we had seen how OFDM converts the frequencies selective healing channel into a frequency flat channel across each subcarrier. Hence, the next system model is given Y 0 is equal to H 0 times zero, then Y 0 is the received symbol across the 0 th subcarrier, H 0 is the channel coefficient corresponding to the 0 th subcarrier, H 0 is the symbol loaded onto the 0 th subcarrier. Similarly, Y 1 is equal to H 1 times H 1 so on and so forth in general, Y k is equal to H K times X K across the K th subcarrier and so on. We have until Y N minus 1 is equals to H N minus 1 times X N minus 1, that is the total of N subcarrier.

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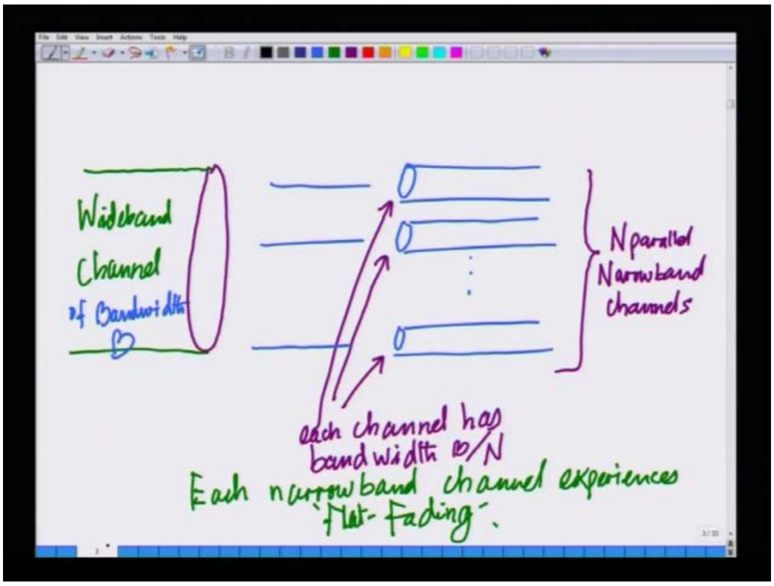

And we said thus, this essentially converts a wideband channel of bandwidth B into N parallel narrow band channels of bandwidth B by N. Such that there is no inter symbol interference across any narrow bind channel and detection is easy across each narrow bind channel, that is the big advantage of this OFDM system.

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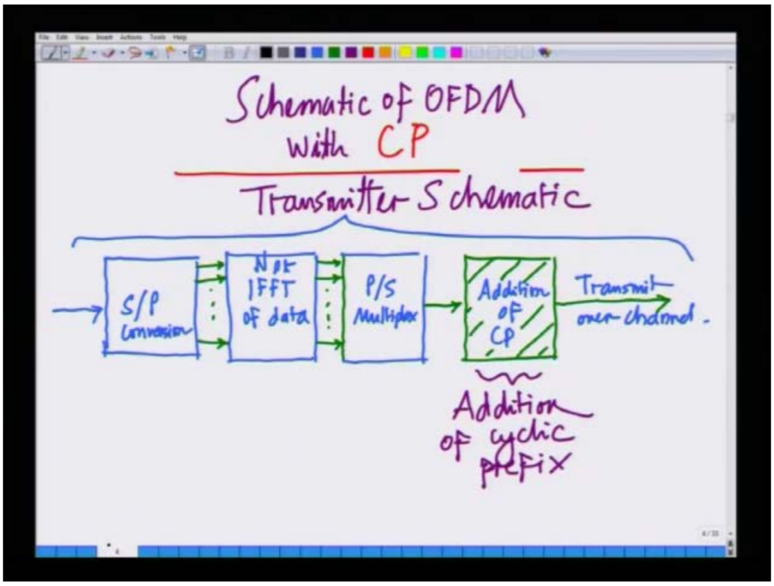

And we also said that, the system architecture of the system schematic is now modified to with the addition of the cyclic prefix block that is, we need to take prefix that is, we need to prefix a string of symbols in front of the OFDM symbol to avoid inter OFDM symbol interference.

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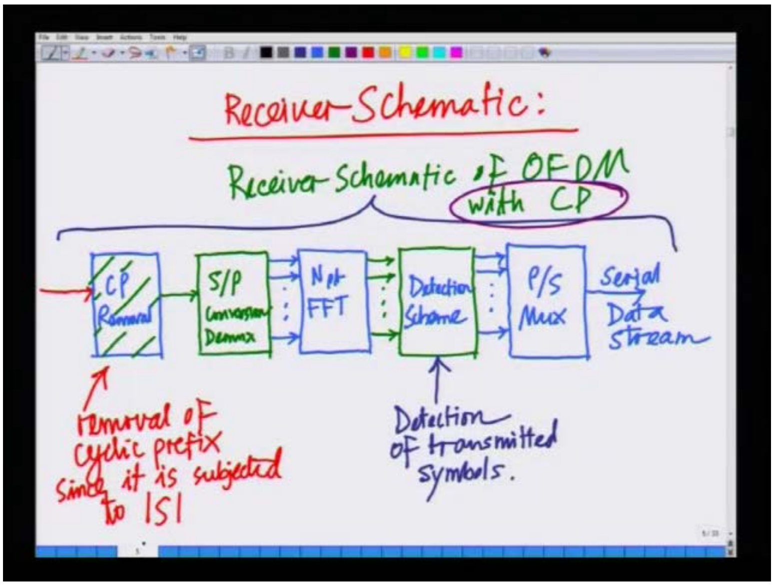

And at the receiver, we removed outputs corresponding to the prefix and we also added block for the detection of the symbols corresponding to the each subcarrier before multiplexing them on to converting them from parallel to serial and passing this data on to the higher layers.

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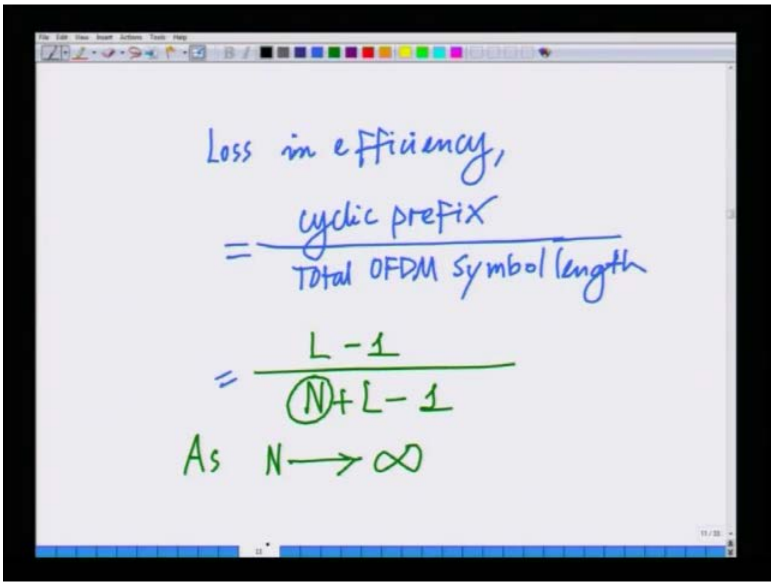

And also we said that, this cyclic prefix slightly tricky in the sense that, when you add a cyclic prefix since you are repeating symbols, they do not carry any additional information. Hence, adding the cyclic prefix results in the loss of effective information but we said we can compensate for that by increasing the OFDM number of subcarrier to the block length.

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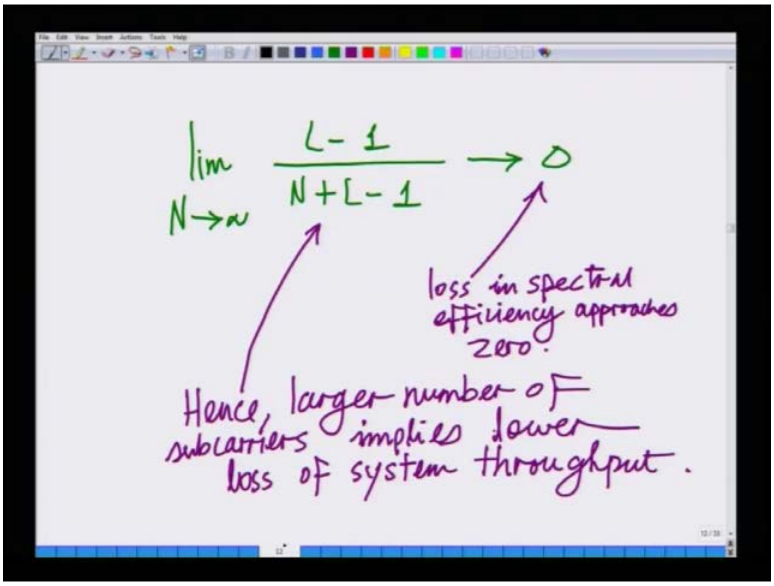

As the number of subcarriers increases we had seen that, there is loss in spectral efficiency hence, progressively it is 0.

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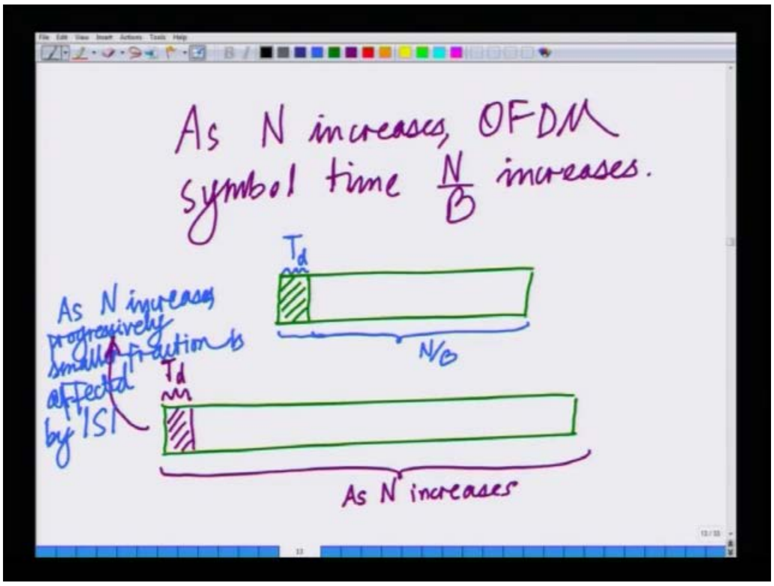

And what this means also is essentially, that has you adding as you are increasing the number of subcarriers, the OFDM symbol time is progressively increasing. So that, the effect of inter OFDM symbol interference is now restricted to smaller and smaller fraction of the OFDM symbol that is what, means to increase number of subcarrier.

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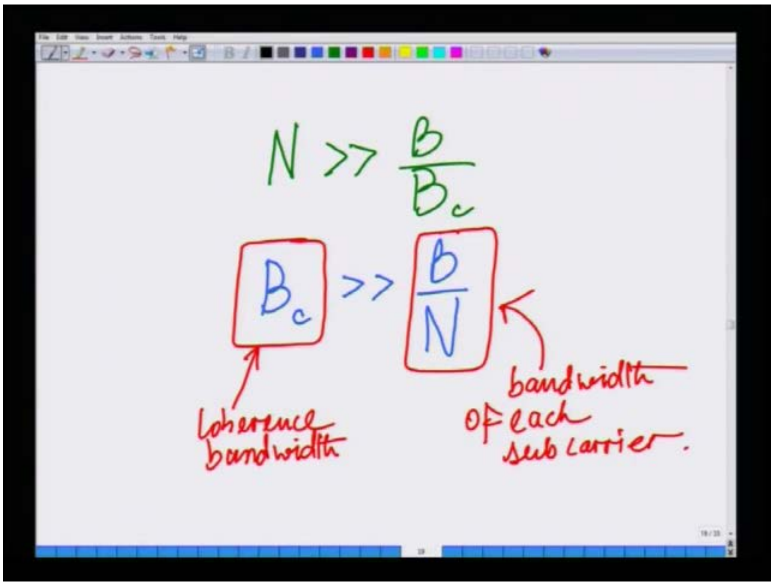

And we also said that, this essentially means that, the bandwidth of each subcarrier that is, B over N is much smaller than the coherence bandwidth. Thus, ensuring frequency flat fading across each subcarrier, that is essential idea behind this OFDM system.

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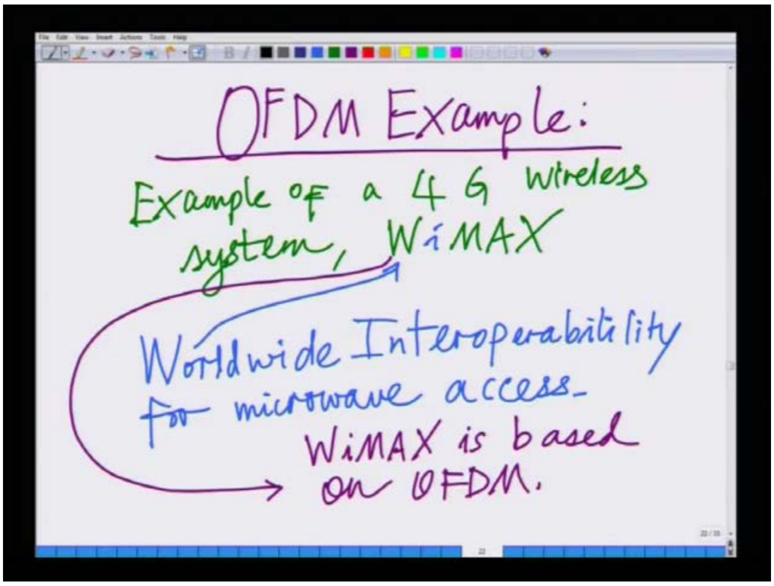

And finally, we started to look at an example of OFDM system, we considered 4G WiMAX scenario. We said WiMAX is the 4G standard, it is the 4th generation wireless communication standard.

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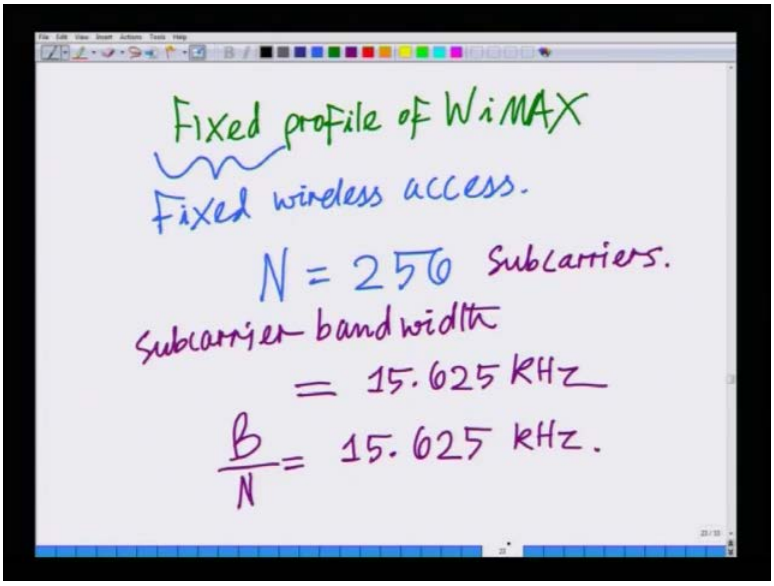

And we started looking at fixed profile that is, WiMAX has several profile, we started looking at one of the profile, which is the fixed profile of the WiMAX standard profile. So, let us continue with that example so continuing with that example.

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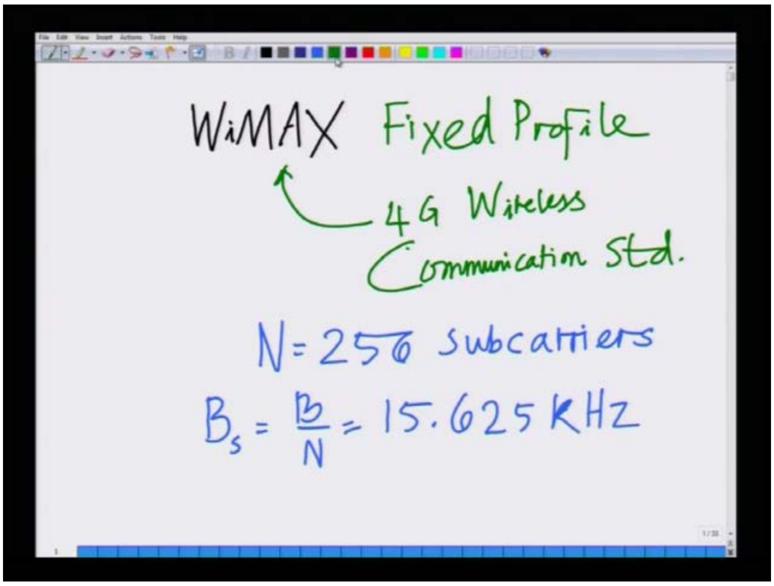

We said that, the WiMAX fixed profile of WiMAX the WiMAX we said with considering WiMAX, the fixed profile WiMAX is 4G mobile WiMAX is generally, 4G wireless communication standard, it is a 4G wireless standard communication standard. And this profile this fixed profile of WiMAX has N equals 256 subcarriers and we also said, with the bandwidth per subcarrier that is, B s is 15.625 kilo Hertz. So, B s which is nothing but B over N equals 15.625 kilo Hertz so B s, the bandwidth per subcarrier 15.625 kilo Hertz.

Now, we can see this 15.625 kilo Hertz is much less than the coherence bandwidth of the system, which is around 200 to 300 kilo Hertz. Hence, we can safely say that, each subcarrier experience frequencies flat fading.

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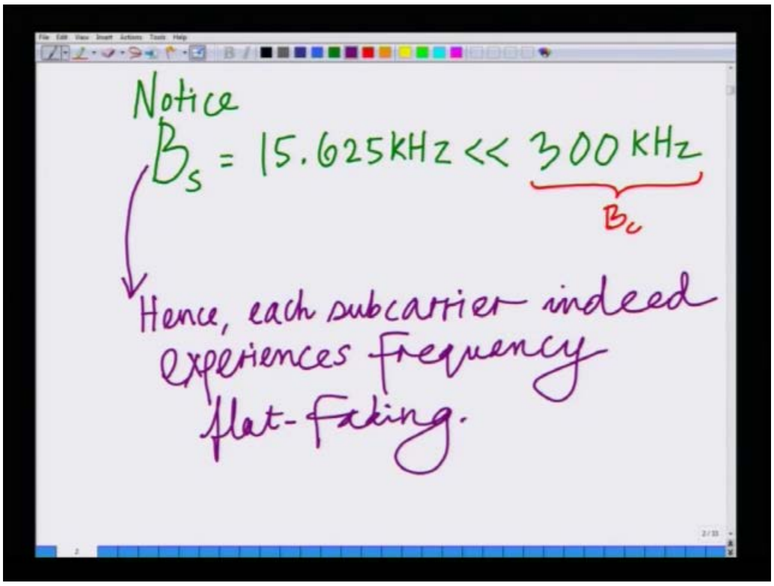

So, we notice that, the B s equals to notice B s equals 15.625 kilo Hertz, which is much smaller than the coherence bandwidth, which is approximately 300 kilo Hertz. So, this is much smaller than the coherence bandwidth, which is approximately around 200 to 300 kilo Hertz. Hence, we can safely say that, in this fixed profile, each subcarrier experiences frequency flat fading. Hence, hence each subcarrier indeed experiences frequency hence each subcarrier indeed experiences frequency flat fading because the bandwidth per subcarrier is much less than the coherence bandwidth.

Now, what is the bandwidth of the system, what is the total bandwidth of the system we know that, the total bandwidth of the system is nothing but the bandwidth per subcarrier into the number of subcarriers.

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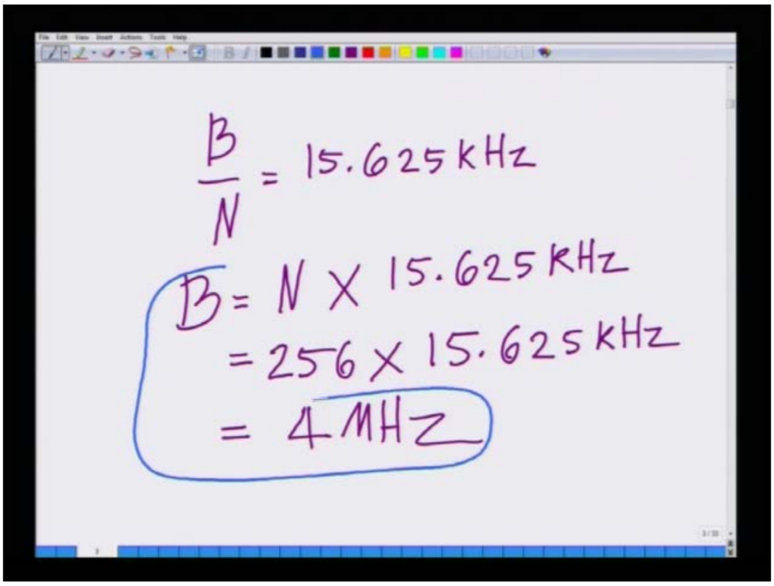

So, we have B by N equals 15.625 kilo Hertz, it seems B is equal to N times 15.625 kilo Hertz, which is essentially equal to we said, n equals 256 subcarriers so this is 256 into 15.625 kilo Hertz this is nothing but 4 mega Hertz. Hence, the bandwidth of this fixed profile OFDM may is B equals 4 mega Hertz hence, we can see this bandwidth is 4 mega Hertz, which is a wide band channel is much larger than the coherence bandwidth of 300 kilo Hertz.

By dividing this into N subcarriers, 256 subcarriers of bandwidth 15.25625 kilo Hertz each, this system in ensuring that, each subcarrier experiences only flat fading and not equals to selective fading. Thus, the total bandwidth B is 4 mega Hertz hence now, let us compute some other parameters. What is the OFDM symbol time without the symbol time that is, before you add the cyclic prefix, what is the OFDM symbol time.

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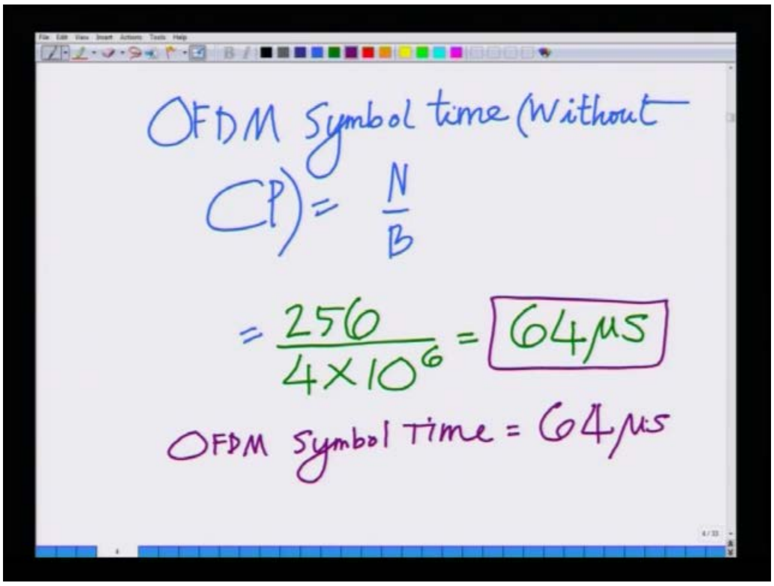

So, OFDM symbol time without cyclic prefix that is, without cyclic prefix is nothing but N over B. So, OFDM symbol time without cyclic prefix is N over B, which is essentially equal to 256 which is essentially equal to 256 divided by 4 mega Hertz, which is 4 into 10 to the power of 6. So, OFDM symbol time is 4 mega Hertz 256 divided by 4 mega hertz which is nothing but 64 micro seconds, this is nothing but 64 micro seconds.

So, this OFDM symbol time is basically 64 micro seconds but this remember, comprises only of N samples and this is before the addition of the cyclic prefix. Now, we said the cyclic prefix depends on, what is the channel delay spread the cyclic prefix has to be greater than the channel delay spread.

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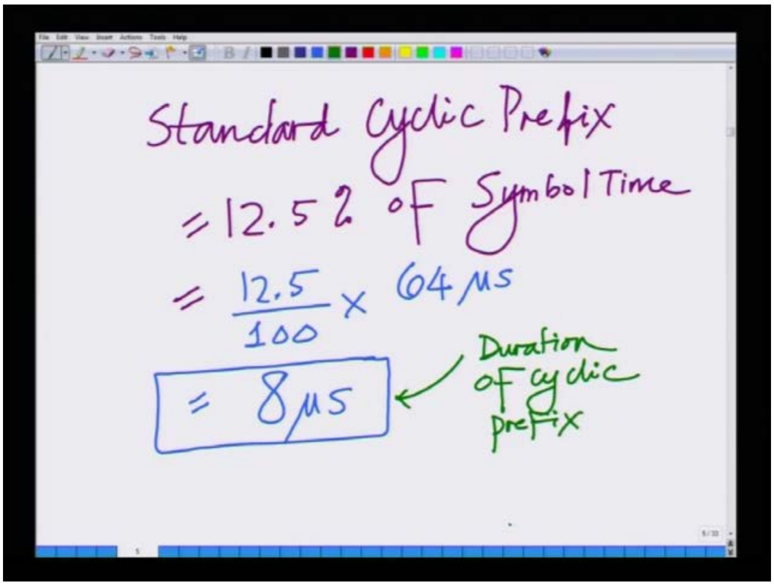

So, the cyclic prefix in this OFDM symbol, the standard cyclic prefix cyclic prefix prefix in WiMAX in WiMAX standard cyclic prefix is 12.5 percent of symbol time equals twelve point five percent of symbol time, which is essentially equal to 12.5 divided by 100 into 64 micro seconds. Thus essentially, 12.5 percent is nothing but is one eighth which essentially, 8 micro seconds. Hence, the duration of the cyclic prefix, this is nothing but duration of this is nothing but the duration of the cyclic cyclic prefix.

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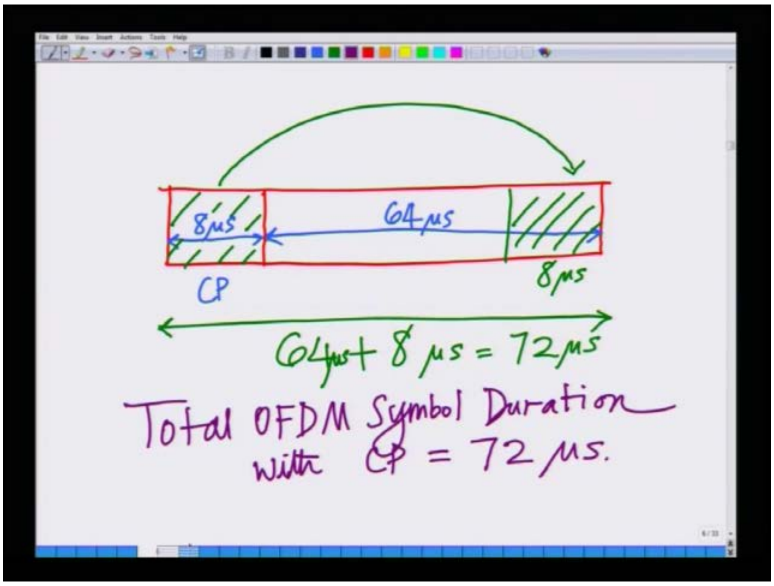

What we says is, I have an OFDM symbol I have an OFDM symbol, in which there is 64 micro seconds of actual symbol, this is the actual symbol and there is 8 micro seconds, this is the cyclic this is the cyclic prefix. In fact, this 8 micro seconds is drawn from the last 8 micro seconds, only last 8 micro seconds of the OFDM symbol is taken from here, not removed but simply copied and prefix, it is not removed it is simply copied and prefix before the OFDM symbol.

So, the net now becomes 64 plus 8, 64 micro seconds plus 8 micro seconds equals 72 micro seconds hence, a net symbol duration, net OFDM symbol duration that is, the net that is the total OFDM symbol duration with cyclic prefix equals 72 micro seconds. Total OFDM symbol duration with cyclic prefix is now 72 micro seconds now, what is the number of samples in this cyclic prefix.

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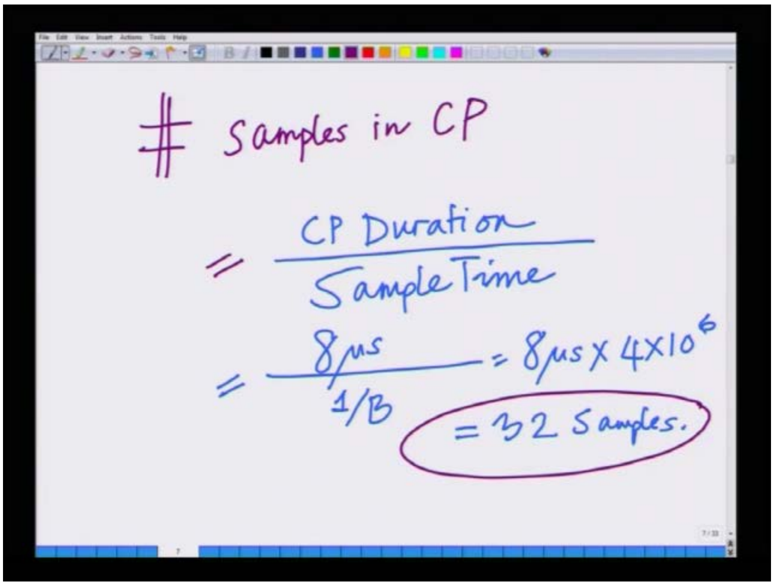

That can also be computed number of samples is nothing but that is nothing but the duration of CP divided by sample times that is but nothing but CP duration divided by sample time. CP duration we saw is 8 micro seconds, sample time is nothing but 1 over B which is 4, B is 4 mega Hertz. Since this is nothing but 8 micro seconds by 1 over B, which is 8 micro seconds into B, which is 8 micro seconds into 4 into 10 to the power of 6 which is nothing but 32.

Hence, total number of samples in CP equals 32 samples we know that, the OFDM symbol without CP is prefix contains 256 samples that is, the size of the IFFD, we add 32 samples of cyclic prefix.

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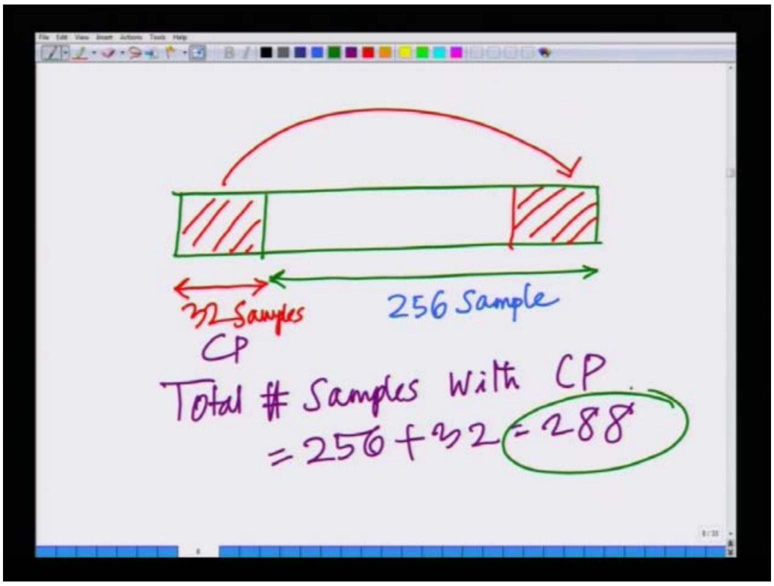

So, again drawing a similar figure, this is the 256 this is the 256 sample OFDM symbol, what we are doing here is essentially, we adding 32 samples of cyclic prefix. And these are taken from the from this part so this is 32 samples and this is the cyclic prefix and tends total number of samples samples with cyclic prefix in one OFDM symbol equals 256 plus 32 equals 256 plus 32 equals 288 samples. That is the total number of samples in this OFDM symbol with the cyclic prefix.

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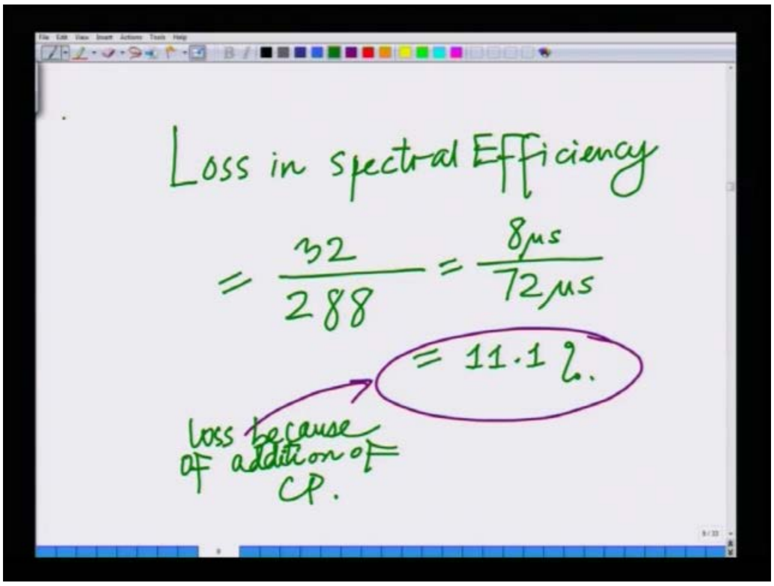

Hence, the loss inspectal efficiency the finally, what we have compute is the loss inspectal efficiency why is there loss inspectal efficiency is. Remember, cyclic prefix itself conveys no information hence, all added cyclic prefix symbol loss inspectal efficiency that is nothing but number of symbols in CP divided by total number of symbols that is 288, which is also the same as the CP duration that is, 8 micro seconds divided by the total number of OFDM symbol duration that is, 72 micro seconds, which essentially 11.1 percent.

So, roughly 11.1 percent is lost, because of addition of CP so this is the essentially loss, because of addition of CP. This is 11.1 percent is essentially, the loss in effective information rate of the system, because of the addition of cyclic prefix, symbols of the cyclic prefix, themselves convey no information. And as we saw, this loss can be progressively brought by increasing the number of subcarriers that is, if I have N equal to 256, 500, 1200, 24 subcarriers.

As the number of subcarriers is increasing, this loss in terms of throughput keep progressively decreasing. Hence, that covers the basics of OFDM, which we talked about what OFDM is, how to what is the motivation behind OFDM. We talked about that, we introduced the multi carrier modulation system and and then we introduced what are the problems implementation problems of this multi carrier modulation. And how OFDM removes those problems or how of how OFDM essentially makes the implementation of such a system easier by the implement by the introduction of IFFD at the transmitter and the receiver.

And also, we demonstrate the use of cyclic prefix and how the use of cyclic prefix removes the effects of inter OFDM symbol interference so we have so this essentially completes an introduction to OFDM. Now, you want to look at some other extensions to an OFDM system for instance, now what do you want to start looking at is, we have looked previously at a MIMOS system that is, a Multiple Input Multiple Output wireless communication System. Now, what we want to look at is, we want to also look at, how can MIMO be coupled with OFDM. That is, how can we have a MIMO OFDM system that is, both working together in a communication system.

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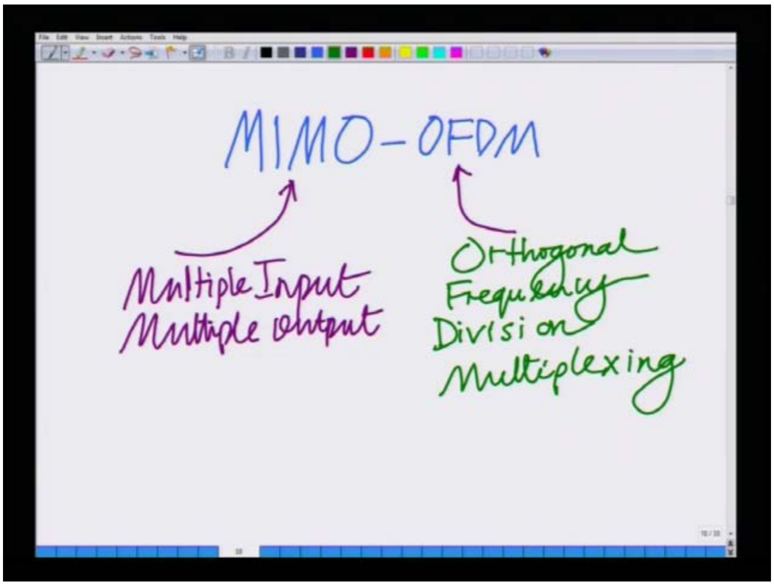

So, we want to look at next topic we want to look at is MIMO OFDM where, MIMO has already knows stands for Multiple Input Multiple Output wireless Systems and OFDM is to remind you, stands for Orthogonal Frequency Division. So, we know that, MIMO stands for Multiple Input Multiple Output wireless communication system it is nothing but having multiple antennas of the transmitter, multiple antennas of the receiver. Then we also have OFDM, which is Orthogonal Frequency Division multiplexing, which converts a frequency selective channel into a set of parallel fading channel.

So now, we want to combine these two technologies to achieve much higher throughput and much easier abrasive processing at the receiver alright. So, the motivation behind MIMO is to achieve the higher throughput, motivation behind OFDM is to convert frequency selective into flat fading parallel set of parallel flat fading channels. So, we couple MIMO and OFDM to achieve both of them that is, high throughput as well as simplified processing at the receiver that is, converting the frequency selective fading channel into a set of parallel flat fading channels.

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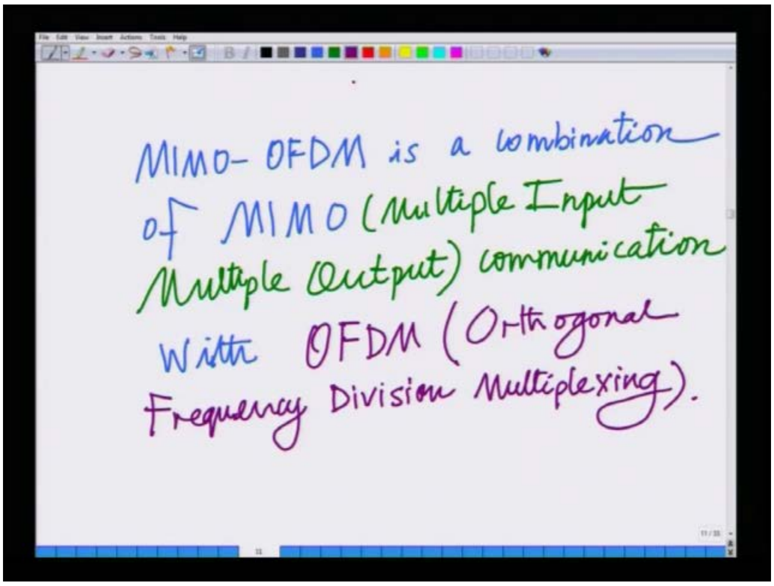

So hence, let me write it down MIMO OFDM is a combination of MIMO with OFDM is a combination MIMO OFDM is a combination of MIMO, which is Multiple Input Multiple Output, it is a combination of MIMO which is Multiple Input Multiple Output communication with OFDM, OFDM is stands for Orthogonal Frequency Division Multiplexing. So, MIMO OFDM is the definition in the sense, it is a combination of MIMO, which is Multiple Input Multiple Output communication with OFDM, which stands for Orthogonal Frequency Division Multiplexing.

And as we also as we already said, OFDM converts a frequency selective channel into a set of parallel flat fading channel. MIMO OFDM converts a MIMO frequencies selective channel into a set of parallel flat fading MIMO channels alright. So, in MIMO OFDM we can with the time dominie channel, is the MIMO frequency selective channel and MIMO OFDM converts this MIMO frequency selective channel into a set of parallel flat fading MIMO channels alright.

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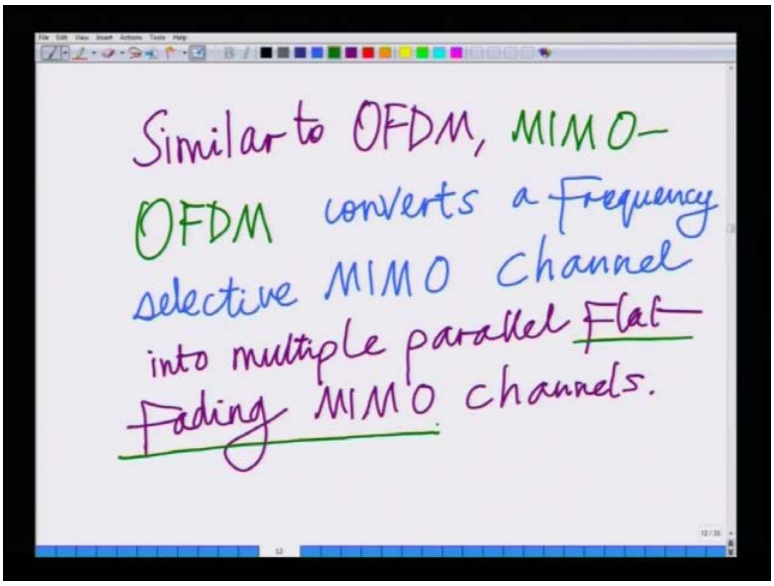

So, similar to OFDM, MIMO OFDM MIMO OFDM converts a frequencies selective MIMO channel converts a frequency selective MIMO channel into multiple parallel flat fading channels into multiple parallel flat fading into multiple parallel flat fading. The key here is, flat fading MIMO channel, so it converts a MIMO frequency selective channel into a set of parallel flat fading MIMO channel thus, simplifying receiver processing alright.

Now, in the absence of a flat fading MIMO channel, one needs to eliminate MIMO inter symbol interference, this this essentially implies that you need a MIMO equalizer alright. So, what MIMO OFDM does is that, it removes the need or it essentially simplifies the receiver processing by by converting this into set of flat fading MIMO channel thus, making it unnecessary to have a, to implement MIMO equalizer which much complicated.

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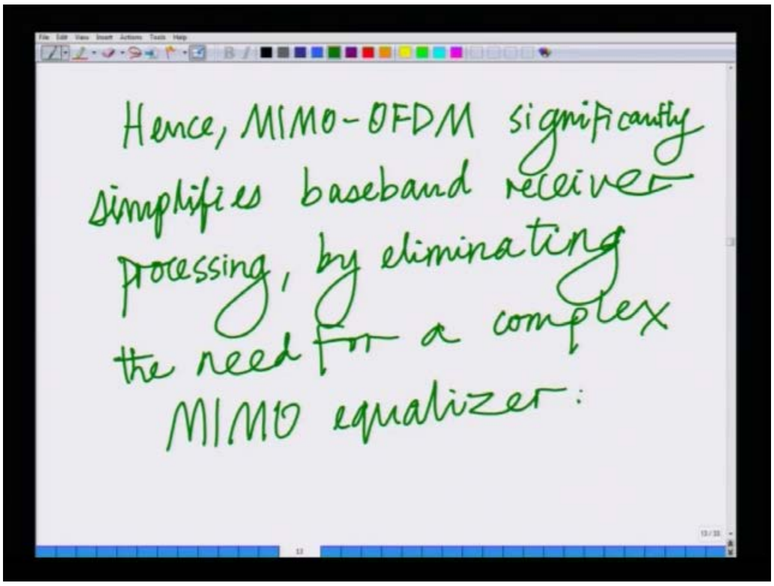

Hence, thereby hence MIMO OFDM significantly simplifies simplifies baseband MIMO baseband receiver processing simplifies baseband receiver processing by eliminating the need for a complex MIMO equalizer. It simplifies base band processing by eliminating the need for a complex MIMO equalizer that is, this MIMO inter symbol into this MIMO frequency selective fading channel in fact, causes MIMO inter symbol interference.

Hence, in the presence of MIMO inter symbol interference, one needs a MIMO equalizer thus, by removing the need for a MIMO equalizer, this significantly simplifies base band receive processing that is, it it is eliminates MIMO inter symbol interference alright. So, that is the essential advantage of MIMO OFDM now of course, to understand it, first we have to understand how does a MIMO frequency selective channel look. We have to understand, we have to get an in depth understanding of, what is the nature of MIMO frequency selective channel, which causes MIMO inter symbol interference. So, first what we are going to start with, we are going to start with an introduction to the MIMO frequency selective communication channel model.

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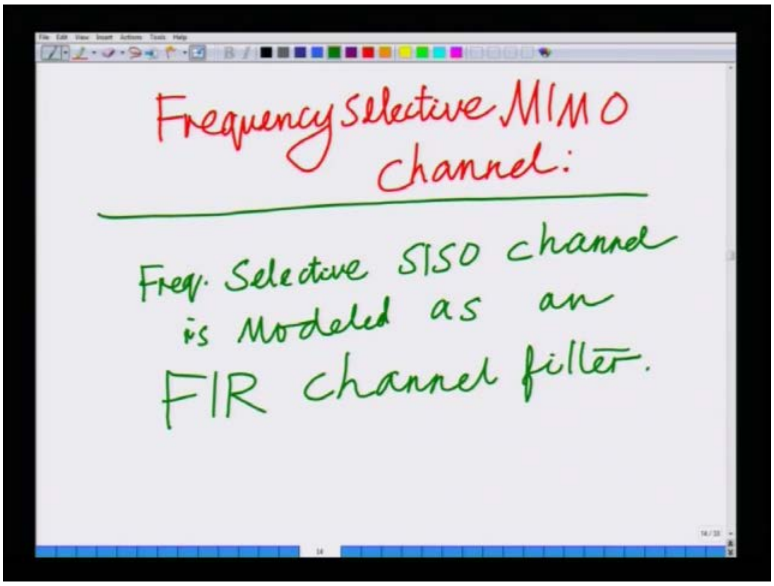

So, I am going to start with the frequency I am going to start with the frequency selective MIMO channel. Now, remember the frequency selective channel, a single input single output channel is modelled as follows, to let me let me remind you that, a frequency selective SISO channel is modelled as an FIR filter it is modelled as an FIR. Remember, the frequency selective SISO channel is modelled as an FIR filter.

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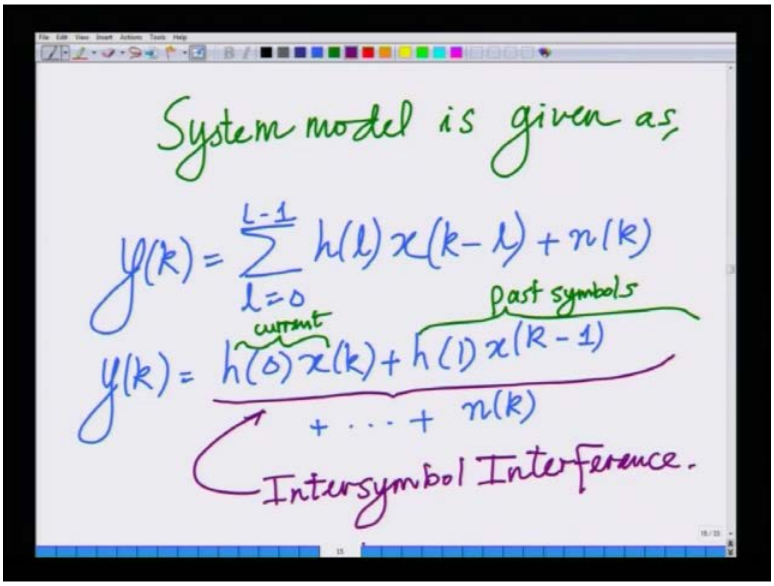

In fact, the output is given, the output system model is given as the system model is given as y k equals summation l equals 0 to l minus 1, h of l x k minus l plus n k, which essentially translates to, if you look at y k this means, y k equals h 0 x k plus h 1 x k minus 1 plus so on plus n k. And this we said, each output symbol depends on both the current symbol and also the past symbols x k minus 1, these are the past symbols x k x k minus 1 x k minus 2 and so on.

So, the current symbol output y k depends on both x k, which is the current symbol and also the past symbol which essentially means that, there is inter symbol interference. So, this essentially means that. So, this essentially means that there is inter symbol. So, this essentially means that, there is inter symbol interference in this channel tap which is modelled as an FIR filter. Hence now, how do we model a MIMO frequency selective channel, the natural answer is MIMO frequency selective channel is modelled as a MIMO FIR filter where, each channel tap is MIMO channel matrix.

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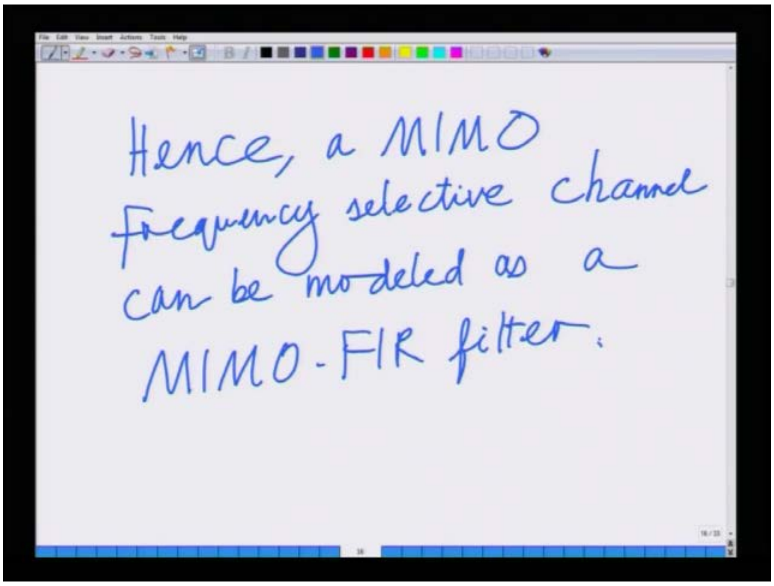

Hence, a MIMO hence, the first result that you want to present hence, a MIMO frequency selective channel is or can be modelled as a MIMO FIR filter. Hence, a MIMO frequency selective channel can essentially be modelled as a can be modelled as a MIMO FIR filter. What does it means, so if I look at the received symbol vector at MIMO receiver, remember we said in a MIMO system, we have multiple transmitter antennas, multiple receiver antennas.

Hence, the transmit transmitted symbol is nothing but it is a vector comprising of the transmitted symbol, these receive antenna. And this receive symbol is also a vector corresponding to receive symbol at receive symbol at all the receive antennas.

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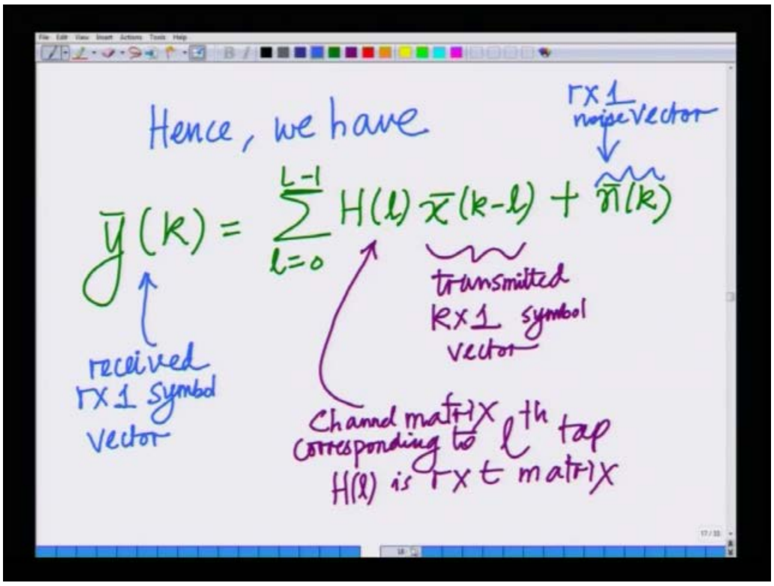

Hence, the system model hence, we have the receive vector now y k bar y bar k equals summation l equals 0 to capital L minus 1 h of l x bar of k minus l plus n bar of k where, y bar k is received r cross 1 symbol vector. This is the received r cross 1 symbol vector, this is the transmitted k cross 1 this is the transmitted k cross 1 symbol vector and h k is the channel matrix. Now remember, this is the l th tap but this is the channel matrix corresponding to the l th tap remember, this is h l is nothing but the l th tap.

But, in this MIMO frequency selective channel, it is a matrix so this is the channel matrix this is the channel matrix corresponding to l th tap. In fact, h l is an r cross t matrix in fact, h l is an r cross t matrix and n bar is nothing but this is nothing but the r cross 1 noise vector. This is nothing but the r cross 1 received noise vector that is, n bar k, this is the MIMO frequency selective channel.

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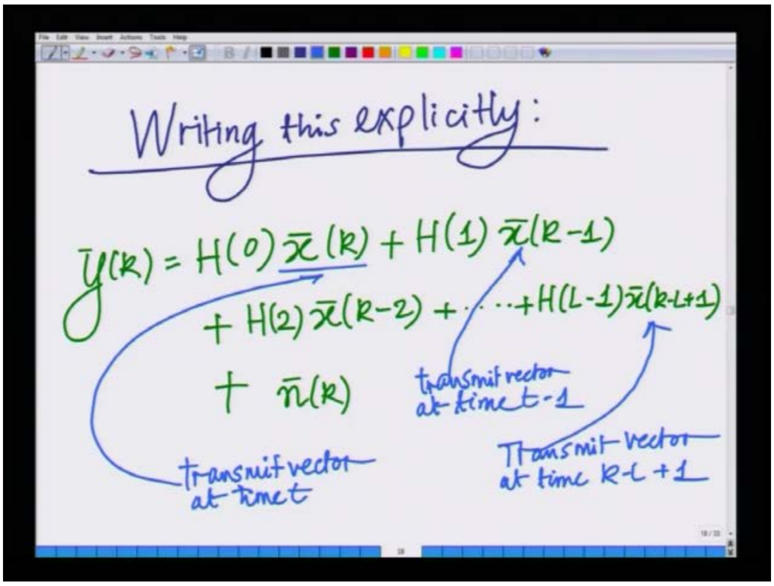

In fact, we can write this explicitly so writing this explicitly so writing this explicitly we can see that, this is nothing but y bar k equals h 0 x bar k plus h 1 x bar k plus k minus 1 plus h 2 x bar k minus 2 plus h l minus 1 x bar k minus l plus 1 plus n bar of k n bar of k. And this x bar of k this x bar of k is nothing but the transmit vector at time t so x bar of k is transmit vector at time t, x bar k minus 1 is vector at time t minus 1, this is transmit t minus 1, x bar k minus l plus 1 is transmit is transmitted time k minus l plus 1, this is the transmit vector.

Hence, y bar k depends not only on x bar k but it depends on x bar k minus 1 x bar k minus 2 so on upto x bar k minus l plus 1. Thus, this is the model of and remember this is the model of inter symbol interface between, it is inter vector symbol interference hence, this is the selective frequencies MIMO channel alright.

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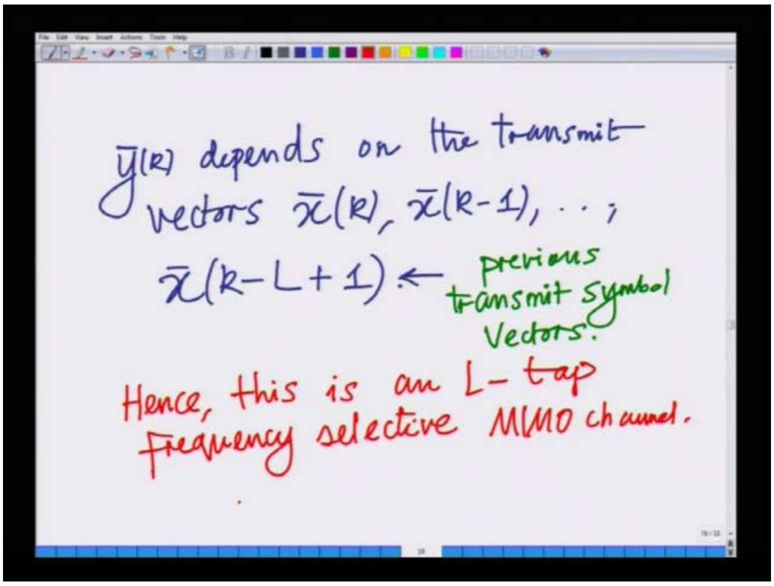

So, each of this so y bar k depends on the transmit vectors x bar k x bar k minus 1 so on upto x bar k minus l plus 1. Hence, it depends on the transmit vector x bar k x bar k minus 1 so on upto x bar k minus l minus 1 that is, the previous transmit vectors. So, which are essentially the previous transmit symbol vectors hence, the above is hence, this channel is an l tap frequency selective MIMO channel. Hence, these are the previous transmit vectors hence, this is an l tap frequency selective hence, this is the model of an l tap frequency selective MIMO channel. Hence, there is ISI between the current and previous transmit symbol vectors, not the symbols but between the vectors.

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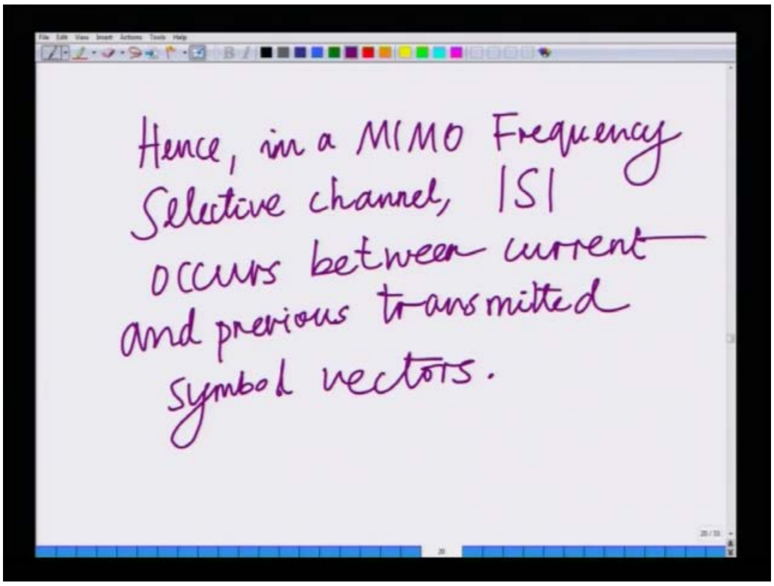

Hence, in a MIMO frequency selective channel, ISI occurs between the current and previous transmitted vectors that is, the inter symbol interference occurs between current and transmitted inter symbol interference between current and previous transmitted symbol vectors. Hence, for a MIMO OFDM system, one needs to perform the IDFT or IFFT perform operation at each transmit antenna. Remember, this symbols are now not simply one symbol but there is one symbol transmitted from each transmit antenna. Hence now, the IFFT perform operation of OFDM has to be perform at each transmit antenna. That is, for the block of symbols each transmit antenna, one has to perform in IFFT operation.

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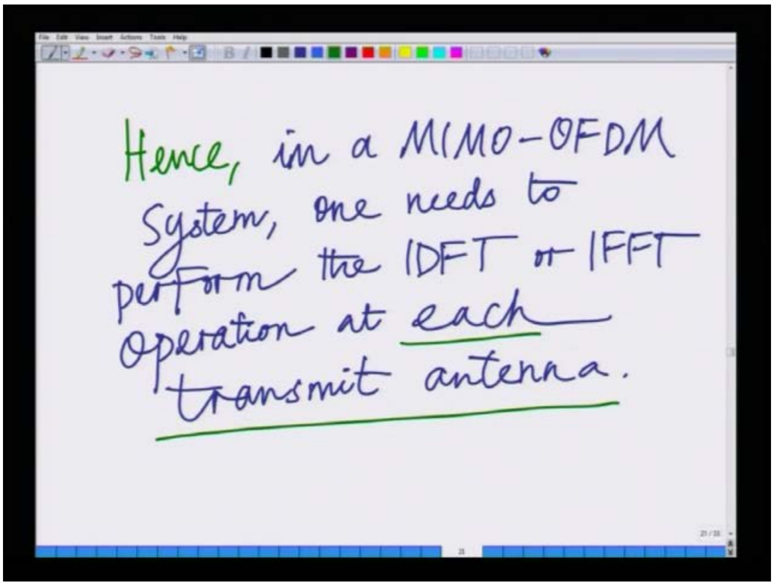

Hence, in an MIMO OFDM system hence in a MIMO OFDM in a MIMO OFDM system, one needs to perform one needs to perform the IDFT or IFFT operation at each that is, what all operations that we had in the OFDM schematic at the transmitter, now have to be perform at each transmit antenna in this MIMO OFDM system that is, at each transmit antenna in this MIMO OFDM system. Hence, let us look at schematic let us look at the schematic of this MIMO OFDM system, let us look at the transmitter schematic.

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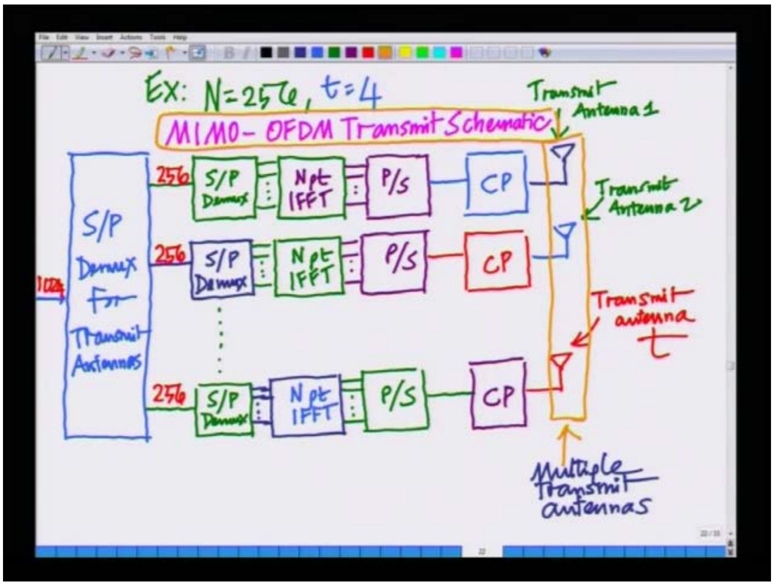

If I look at the transmitter schematic, I am going to have one serial to parallel block to demultiplex amongst the transmit antenna. So, this is the serial to parallel demux or demultiplexing for transmit. This is the serial to parallel demultiplexing for the transmit antennas then now, I will after demultiplexing transmit antennas, these transmit antennas I will again demultiplex to form a block, on which the (( )) perform. So, on each transmit antenna, first I will further demultiplex to form a block so this is S slash P demux, I will have a block of symbols.

On this block, I will perform the N point FFT so in this block, I will perform the N point IFFT essentially. Once I perform the N point IFFT, I multiplex this again similar to what we have done before I multiplex these into parallel to serial. I convert this parallel block to a serial block, once I convert this parallel to serial block, I will add the cyclic prefix. Now, I will add the cyclic prefix that is, at each transmit antenna I am adding the cyclic prefix finally, what I will do is, I will transmit this from the transmit antenna.

So, this is transmit antenna 1, I am going to transmit this from transmit antenna 2 but before that, I have to do this processing before I can transmit this from transmit antenna 2. Similarly, at transmit antenna 2, I am going to do a serial to parallel serial to parallel demultiplexing operation, this is the serial to parallel demultiplexing operation or blocking operation at transmit antenna 2. Then I will do the N point FFT of the symbols, for this is the N point

IFFT for transmit antenna 2 followed by now, take this IFFT samples and convert them from parallel to serial that is, multiplexing.

And now, add the cyclic prefix at the transmit antenna 2 so this is addition of the cyclic prefix at transmit antenna 2. So, this is1first one is transmit antenna 1, second one is transmit antenna 2 and so on and so forth, I have t transmit antennas, at which I have to look all these operations. So, at the t th transmit antenna, I again have the serial to I have a serial to parallel demultiplexing operation. Followed by I have followed by this, I will again have a block of N symbols, which are loaded into N subcarrier, over which I have to do this IFFT at the t th transmit antenna.

Followed by a block of, followed by the N point IFFT at the t th transmitter antenna now, I have again multiplex these so multiplex these. So, I parallel to serial, I multiplex all of them into the same line before of course, I add the cyplipc cyclic prefix now at the t th. So, addition of the cyclic prefix so I add the cyclic prefix now, add the t th transmit antenna and then at transmit this the transmit antenna t. So, this is the t th transmit antenna and in fact, these if we look at these here, these are nothing but my multiple transmit antennas these are nothing but the multiple transmit antennas that is, the front end alright that is, back end that is transmitter.

Only these are the multiple transmitter antennas, before the transmitting on each transmit antenna, I have to perform these OFDM operations which is blocking IFFT. Then again, D blocking that is, serializing addition of CP transmission, so this has to be perform at each transmit antenna essentially. And before that, I have to take all the available symbols and divide them among transmit antennas.

So, lets see, let me consider a system with N equals 256 for instance, let us say I have an example, N equals 256 subcarriers and t equals 4 transmit antennas. So, what I have here is, I have a block of 124 symbols that are coming in so I have a block of 124 symbols that are coming in. Out of this, I have to divide them into 4 transmit antennas so now, I divide 256 symbols among each of the 4 transmit antennas. So, I get N times t symbols in send a block of N symbols to each transmitter antenna perform IFFT, load them on to the subcarriers alright.

And then serialize them, add cyclic prefix, transmit from each transmit antenna, this is now the schematic of the MIMO OFDM transmits schematics. So, let me write that down, this is now the MIMO OFDM this is now the MIMO OFDM this is the MIMO OFDM transmit this is the MIMO OFDM transmitter schematic alright. This is the MIMO OFDM transmitter schematic, how is transmission to be done or the transmit preprocessing to be done in a MIMO OFDM system. And correspondingly now, we will look at, what we have what is the corresponding receive processing that has to be done in this MIMO OFDM system, what is the corresponding receive processing that needs to be done.

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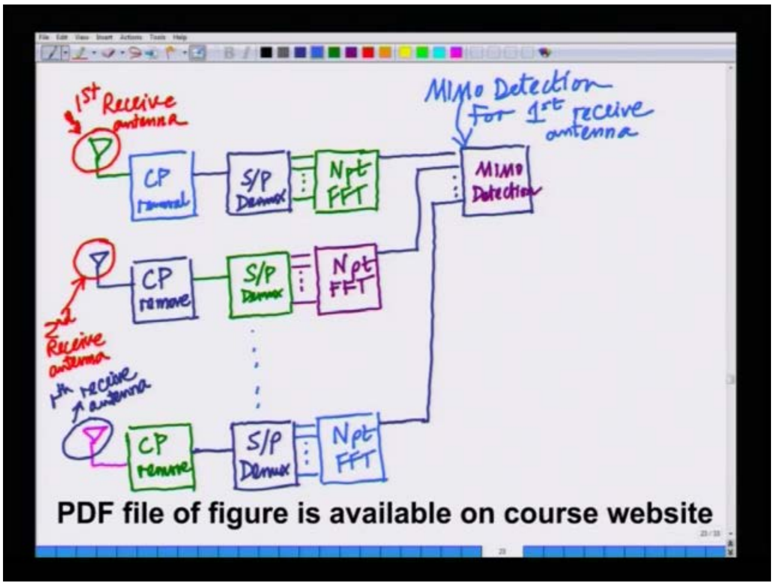

At the receiver, similar to what we had in the OFDM receiver, I will have I will have to remove the cyclic prefix so CP removals, I will have a block to remove the cyclic prefix. Followed by, I will have a block for serial to parallel conversion serial to parallel serial to parallel, which is also nothing but a demux operation alright. So, serial to parallel is nothing but a demux operation so demultiplex them and now here, what I will do is, I will perform the N point I will perform the N point FFT.

And after the FFT, what I have to do is, I have to do the detection I have to do the detection, similar to what we had in a OFDM OFDM receiver. Remember, we said we have to do detection but this is not a simple detection but this is a MIMO detection. Remember, we are dealing with a MIMO frequency selective channel, which is converted into MIMO flat fading channel hence, we have to perform a MIMO detection. I will come to that slightly later but let me illustrate the process at the rest of the receive antenna.

Similarly, we have at the second receive antenna, we have again the removal of the cyclic prefix that is, the CP. CP removal followed by we have the serial to parallel demux, followed by we have the N point FFT. So, this is the first receive antenna, this is the this is the second receive antenna and so on and so forth, we will do it for all the receive antennas. Similarly, at the at the r th receive antenna, what we have is, we essentially have to remove the cyclic prefix that is, CP removal followed by serial to parallel demux alright.

we had removal of the cyclic prefix followed by serial to parallel demux, followed by now we have the N point we have the N point IFF we have the N point FFT and this is essentially perform at the r th receive antenna this is a essentially performed at the r th this is essentially performed at the r th receive antenna. Now remember, as we said we have to perform MIMO detection which means, across each subcarrier we have to perform MIMO detection and that has to be done for all the N subcarriers.

Hence, what I do is for the first subcarrier, let I take the output from the first transmit antenna. Similarly, I take the output across the first subcarrier from the second receive antenna similarly, I take the output from the first subcarrier across the r th receive antenna. And essentially what I will do is, I will process all of these now as the MIMO detection alright. So, what I am doing now is, I am doing MIMO detection for the first subcarrier.

Remember, each subcarrier is now a MIMO systems, I will take from all receive antennas I will collect thus, received symbols corresponding to the first subcarrier and I will perform MIMO detection. Hence, this is the MIMO detection block for the first for the first receive antenna this is the MIMO detection block for the first receive antenna. Similarly, we can perform MIMO detection for the second receive antenna, similarly we have to perform we have to perform MIMO detection for the second sub carrier, MIMO detection for the third subcarrier so on and so forth, MIMO detection for the N th subcarrier, before multiplexing all the symbols. Due to lack of time, I will have to end lecture here, we will continue from this point complete this schematic and proceed on to the next section in this.

Thank you very much.