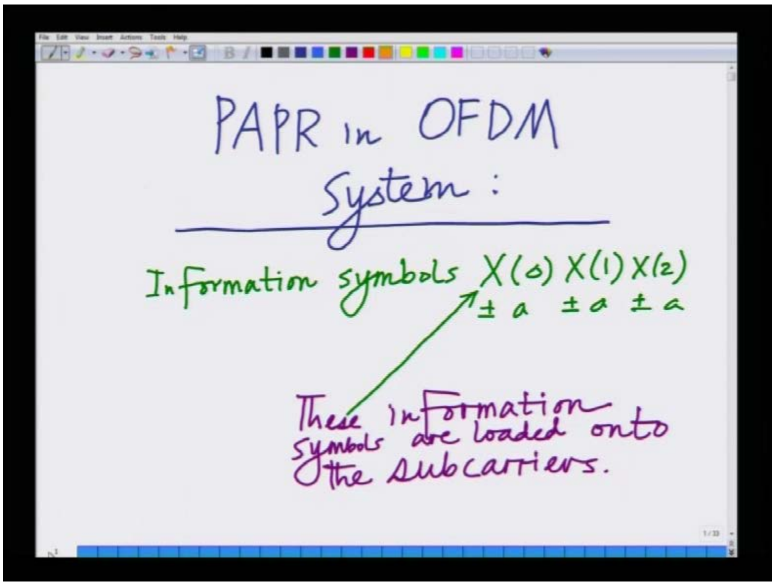
Advanced 3G and 4G wireless communication
Prof. Aditya K. Jagannatham
Department of Electrical Engineering
Indian Institute of Technology, Kanpur

Lecture - 35
SC-FDMA (Contd.) and Introduction of Wireless Propagation

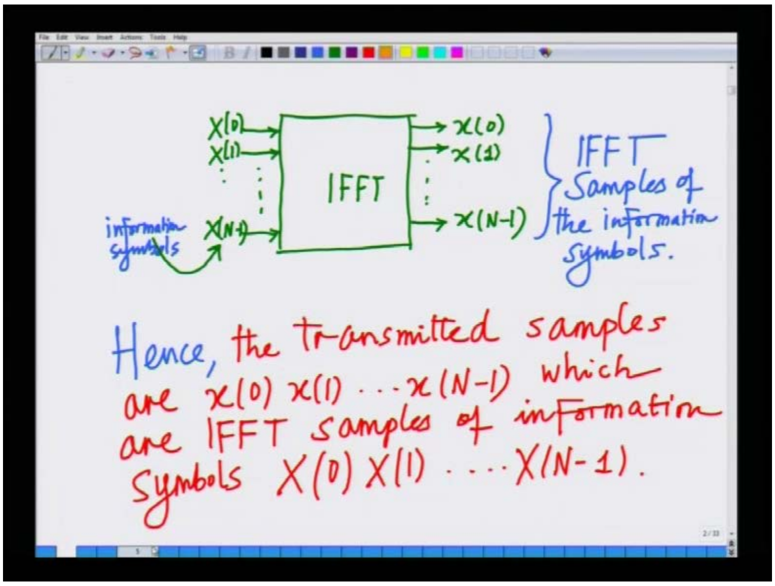
Hello, welcome to another lecture in the course on 3 G, 4 G wireless communication systems.

(Refer Slide Time: 00:21)



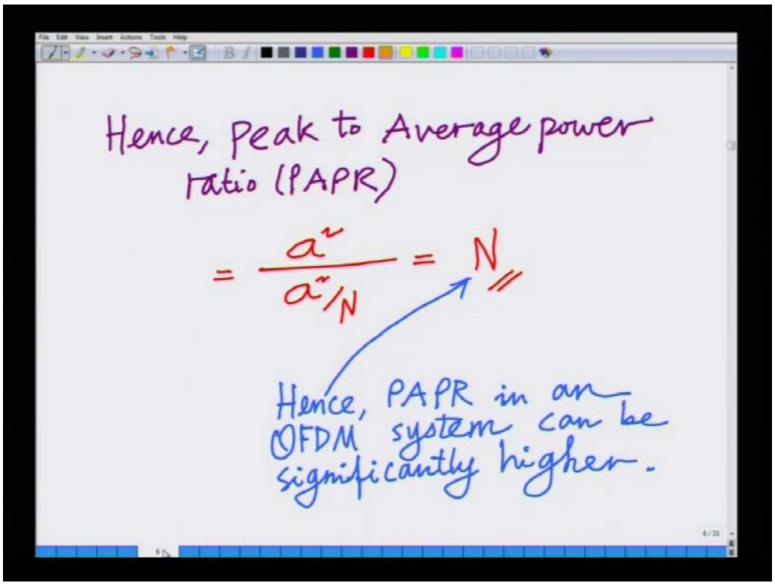
In the last lecture we had looked at the PAPR problem in OFDM systems; that is the peak to amplitude power ratio problem in OFDM system what we said was the information symbols a capital X 0, X 1, X 2 so on are correspond to let us say BPSK modulated symbols plus or minus a plus or minus a plus or minus a.

(Refer Slide Time: 00:37)



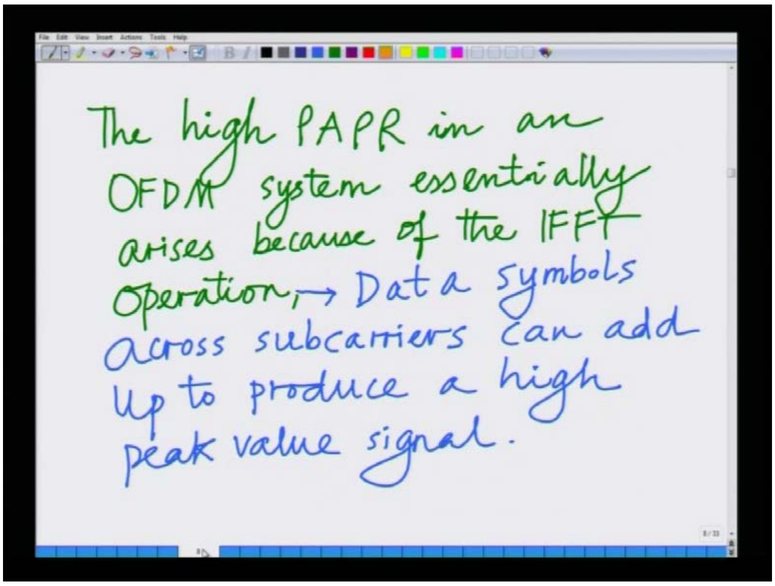
Before we load these information symbols on to the subcarriers and perform an FFT. So, the actual transmitted samples X 0 X 1 X N minus 1 correspond to the IFFT of these information symbols.

(Refer Slide Time: 00:55)



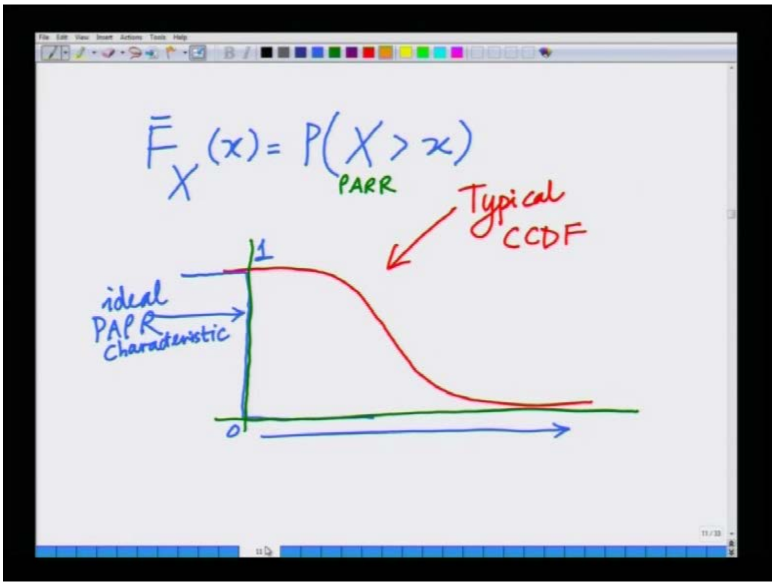
Hence what happens, what essentially happens is when you look at this we have a peak to average power ratio that increases with the number of subcarriers, and that is the as the number of subcarriers increases the peak to average power ratio increases.

(Refer Slide Time: 01:08)



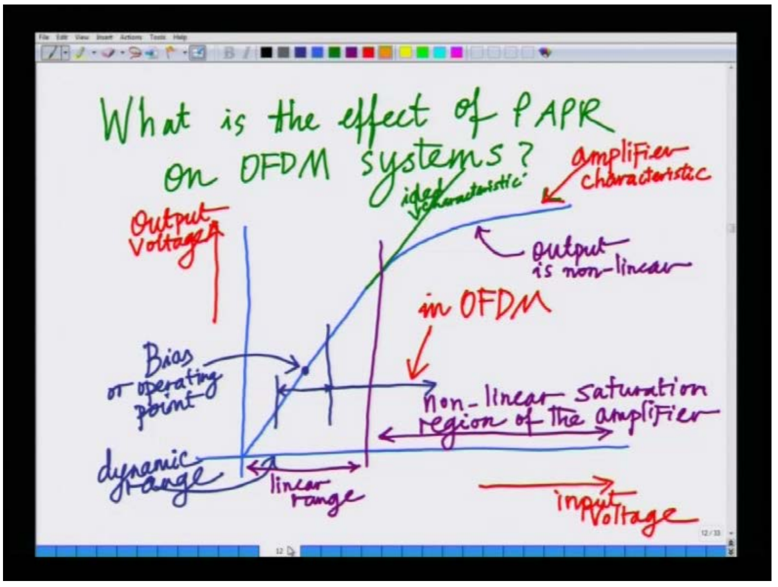
And why is the peak to average power ratio increasing because we said the high peak power raises from the IFFT that is being performed in OFDM, which can occasionally result in a high peak value signal, so because these signals are being combined in the IIFT of the symbols are been combined in the IFFT. They occasionally produced a high peak value signal, which is significantly deviating from the other ways the mean value of the signal. Hence, the peak deviation is much higher over the mean that results in a high ratio of peak to average a high peak to average power ratio in an OFDM system.

(Refer Slide Time: 01:49)



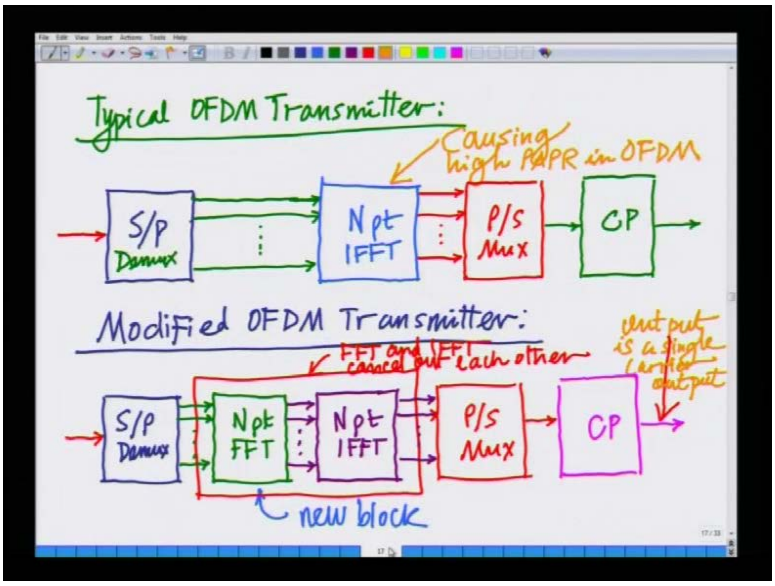
And we also saw that the peak to average power ratio can be measured by this CCDF that is the probability, that the peak to average power ratio is greater than a certain threshold. We also looked at examples for different of how the PAPR CCDF curve looks for different numbers of subcarriers.

(Refer Slide Time: 02:06)



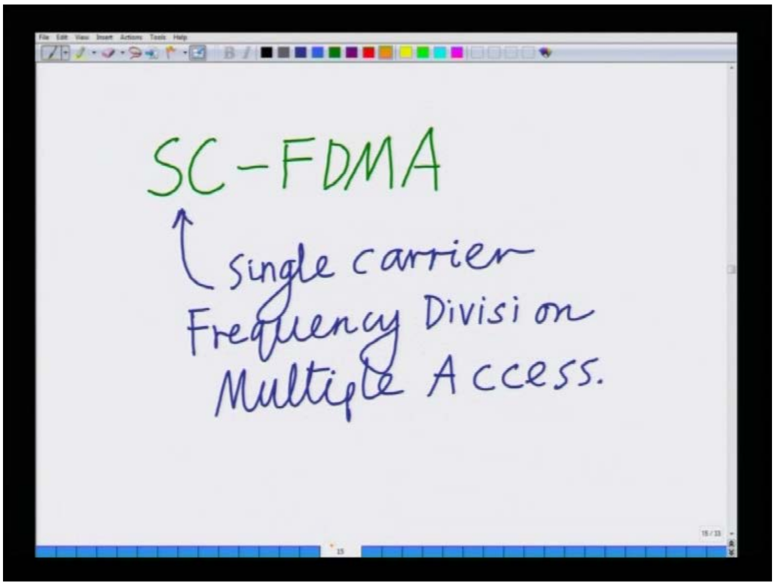
Now, what is the ill effect of PAPR we said the PAPR causes distortion in an OFDM system. Since, every OFDM amplifier has a certain linear range which is biased about the mean. Now, if the deviation about the mean is significantly large that is the peak value occasionally significantly deviates over the mean, then this amplifier crosses over into the saturation or the non-linear range, but its amplification is not linear anywhere. Now, when the amplification is not linear that results in distortion and that results in inter carrier interference; that results in a loss of orthogonality amongst the different OFDM subcarriers, which results as we saw in the case of carrier frequency offset results it is decrease in the net SNR.

(Refer Slide Time: 02:54)



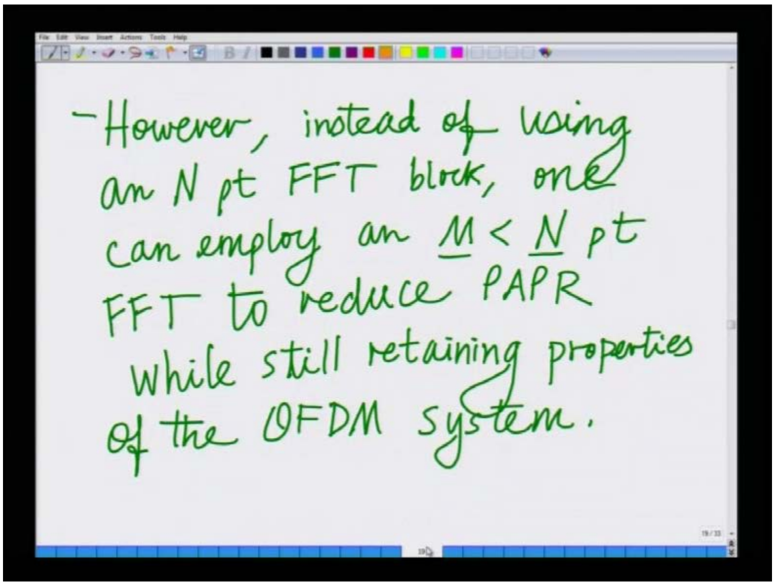
And if we look at a solution, how how can we expect to solve this PAPR?

(Refer Slide Time: 02:58)

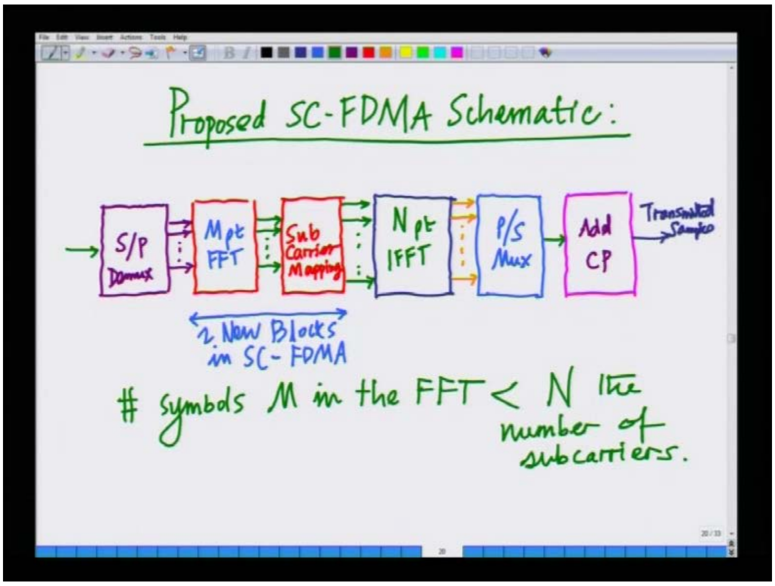


The solution we said is to used single carrier FDMA and that is as follows that is if you observe the OFDM transmitter schematic, if I introduce an N point FFT. Before the N point IFFT the FFT and IIFT cancel and this reduces to a single carrier system, which PAPR is very low. It is almost close to 0 d b that is what we said. Hence, what I want to do is I want to introduce an FFT block before this IFFT. However, I do not want to do an N point FFT because that will go back to single carrier system and intermediate inter symbol interference. I want to do something in between this single carrier system and essentially OFDM.

(Refer Slide Time: 03:40)



(Refer Slide Time: 03:41)

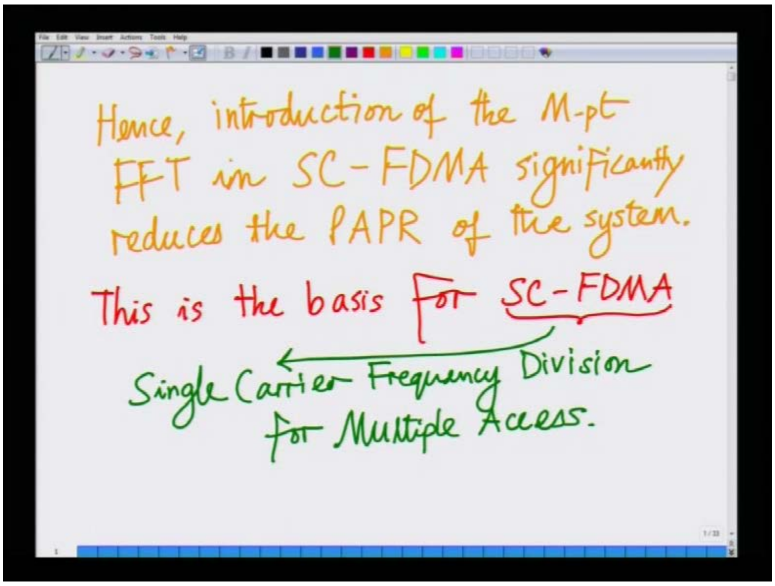


So, I am going to choose an FFT size M, which is much smaller than M. Then map these M symbols on to N subcarriers. Hence, the net schematic looks as follows, I take this M point FFTM symbols perform their FFT map them to the subcarriers. And after I map them to the subcarriers, I can now perform an N point IFFT here. I will perform an N point IFFT here. I will perform an N point IFFT and the rest is exactly like we had earlier, which is out of this N point IFFT will serialize it. That is I will convert from parallel to serial that is a multiplexing operation.

Once I multiplex these signals, I will then add the cyclic prefix and transmit these I will add the cyclic prefix and then transmit these samples, okay? So, these are the transmitted samples and if you look at this these are the two new blocks that we are talking about. If you are looking at this the rest all are conventional OFDM blocks these are the two new blocks in SCFDMA that is these are the the M point FFT and the subcarrier mapping. These are the two new blocks that we are adding in SCFDMA. We also said that the number of symbols in the M point FFT number of symbols, min the FFT is much smaller than N, which is the number of subcarriers.

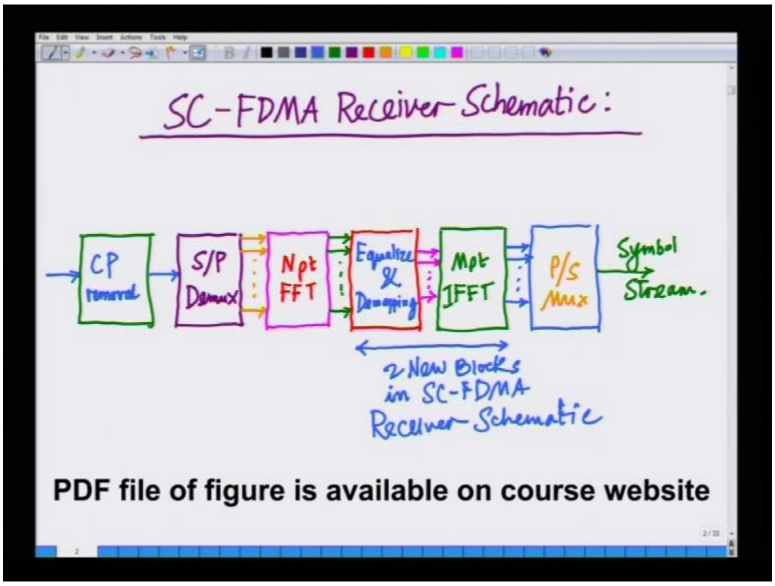
So, the number of symbols M in the FFT is much smaller than because if N equal M, we are going back to a single carrier system and we do not want to do that. So, M which is the number of symbols in the FFT is less than M and this is M point FFT is introduced for the purpose of reducing the PAPR in the OFDM system. After the d f and this step reduces.

(Refer Slide Time: 06:48)



Hence, hence introduction of this M point FFT significantly reduces the PAPR of the M point FFT in SCFDMA significantly reduces the PAPR, significantly reduces the PAPR of the system. And this is essentially transfer this is essentially the techno this is essentially the SCFDMA scheme, which is single carrier FDMA. Hence, this is the basis SCFDMA where SCFDMA as we have talked about stands for single carrier frequency division multiple. This stands for single carrier frequency division for multiple this transfer single carrier frequency division for multiple access, end of this actually reduces the PAPR that is peak your amplitude power ratio of the OFDM system. How does the SCFDMA receiver schematic look? We have looked at the SCFDMA transmitter schematic.

(Refer Slide Time: 09:01)



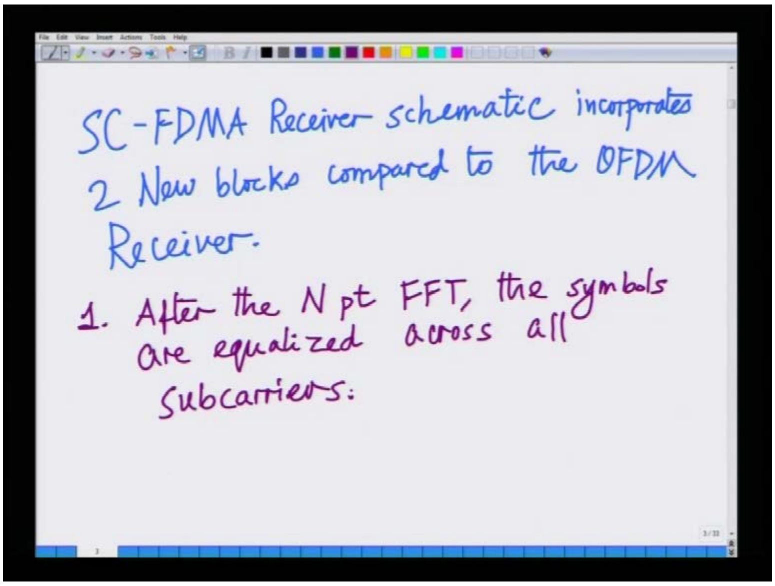
So, now what we want to do is we want to look at the SCFDMA receiver schematics. So, I want to look at the SCFDMA receiver schematic and that SCFDMA receiver schematic looks as follows. What we want to do is we want to essentially add the receiver similar to FDM, once I get the symbols. What I am going to do is I am going to remove the cyclic prefix and followed by I am going to do a serial to parallel de-mux operation that is serial to parallel the multiple; that is I am going to block this. I am going to block into the original FFT size, which is which is original IFFT size, which is N subcarriers.

So, I am going to have similar to what I had earlier, I am going to have hence subcarriers over which I perform N point FFT. So, here I am going to perform N point FFT. Now, after I perform the N point FFT, what I am going to, have to do is I am going to have to equalize these symbols. Previously remember we had a detection, but before detection now we have to equalize because this is signal carrier system. So, we have to equalize and then we have to do a equalize across each subcarrier. Then we have to do a de-mapping.

So, this is equalize and now do a de-mapping de-mapping back to the M symbols. Now, we have to do a subcarrier de-mapping and once we de-map we de-map back into the M, we de-map into M symbols and now we perform the M point, we perform the M point FFT operation after we perform I am sorry we perform the M point IFFT operation and after we perform the M point IFFT operation, I can serialize this. So, I convert from parallel to serial, which is essentially I multiplex this into the data stream or essentially or essentially the symbol stream.

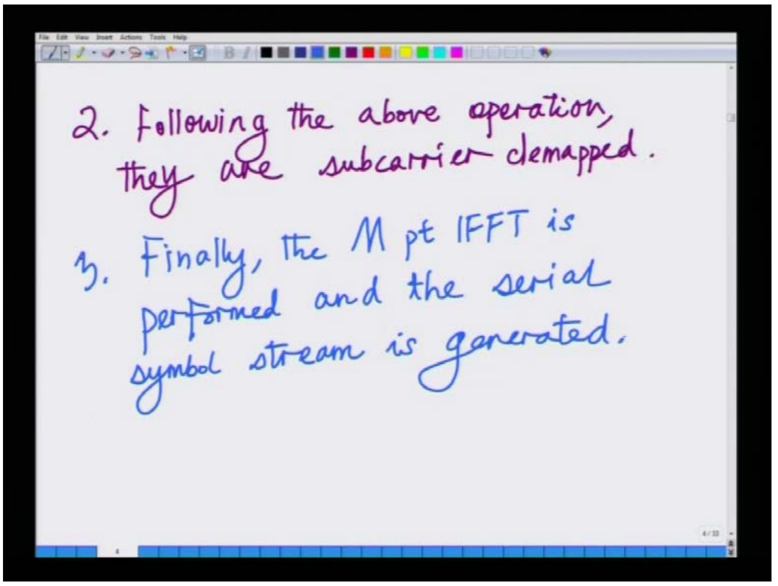
So, this is how the SCFDMA receiver schematic looks. That is cyclic prefix removal serial to parallel demark multiplexing this is same as in OFD M N point FFT. Now I have to equalize and de-map remember into the M symbols. So, I equalize de map perform the M point IFFT multiplex it and I get back my symbol stream. So, if we look at this these are again the two new blocks that we introduce in the two new blocks, in the SCFDMA receiver schematic. These are the two new blocks that we introduce in the SCFDMA receiver schematic and then I get back my symbol, my symbol stream. So, it incorporates two new blocks essentially.

(Refer Slide Time: 13:41)



So, this SCFDMA are so s c f d m a receiver schematic. Incorporates two new blocks compared to the OFDM compare to the OFDM after the after the N point FFT the symbols are equalized. So, first N point FFT, the symbols are equalized across all they are equalized across all subcarriers. Then they are subcarrier de-mapped following the above operation.

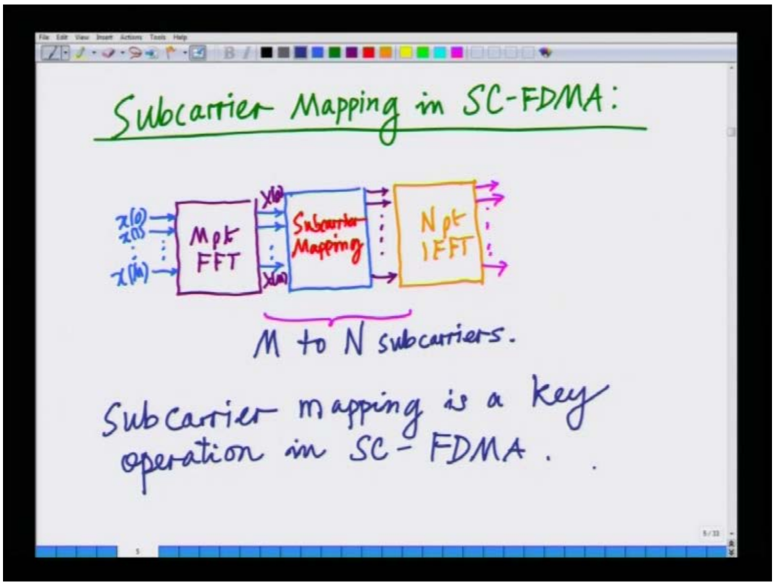
(Refer Slide Time: 15:09)



They are subcarrier de-mapped, this is essentially inverse of the mapping operation that was done at the transmitter. Remember earlier the OFDM transmitter schematic, we had a subcarrier mapping operation. Now, we have a de-mapping operation at the receiver. Finally, the IFFT is carried out and the serial symbol stream is generated. Finally, the M point IFFT is performed and the serial symbol stream. Finally, the M point IFFT is performed and the serial symbols is generated.

So, you feel like that is first after the N point IFFT these symbols are equalized across subcarriers. After equalization that are de-mapped to the M de-map from N to M subcarriers after the de-mapping they are again, you perform the M point. IFFT to invert to reverse the M point FFT operation the receiver and then you then you give back the serial symbol stream at and this serial stream is again generated all right? So, that is how the serial symbol stream is generated and that is one last aspect that we need to talk about in the in this SCFDMA system, which is essentially the subcarrier mapping operation. How are these carriers mapped at SCFDMA transmitted?

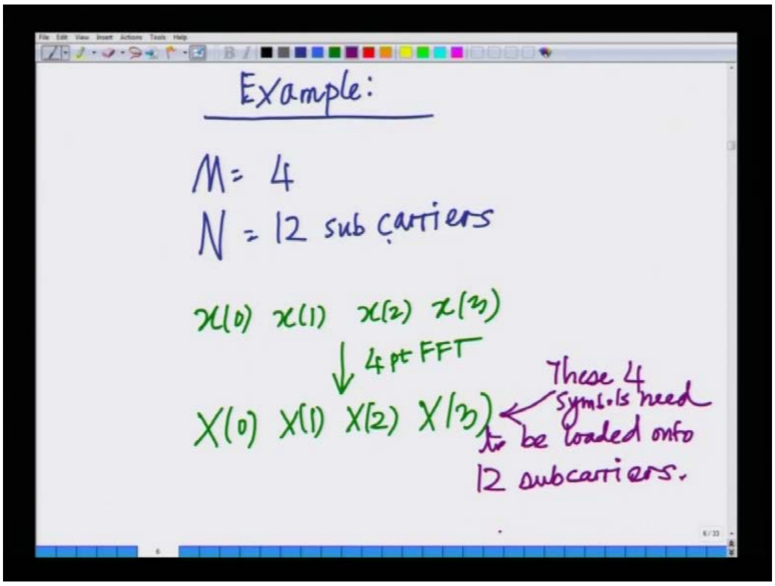
(Refer Slide Time: 17:34)



So, we want to talk about the subcarrier mapping, how are these subcarriers mapped in an SCFDMA? If I look at a subcarrier mapping operation, then what I am I what, I am looking at essentially is let me go back again to my SCFDMA transmitter schematic, I have an incoming stream of I have M symbols X 0, X 1 so on up to X small m, which I am mapping to capital M. So, I am performing here, I am performing the M point FFT and the M point FFT is mean which I am now mapping to the capital N subcarriers. So, here I will have X 0 up to X M, which I am mapping to N subcarriers.

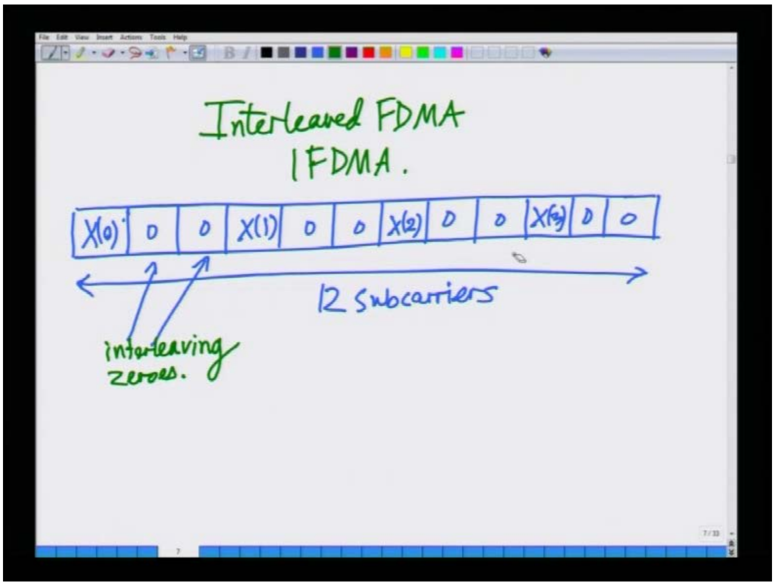
So, here I am performing subcarrier, here I am performing subcarrier mapping and I am subsequently performing the N point IFFT. I am performing the N point IFFT. So, the essential idea is how are we mapping from these capital M capital M to N subcarriers. M to N, how are we mapping these subcarriers, this we can illustrate by so the subcarrier mapping is a key operation. So, this subcarrier mapping is actually a key operation in SCFDMA. Let us illustrate this for a certain example.

(Refer Slide Time: 20:53)



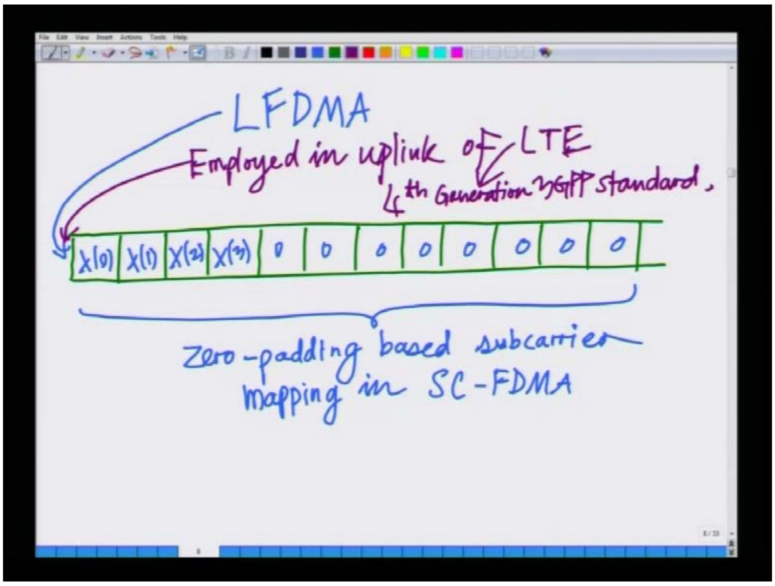
So, as a simple example to illustrate subcarrier mapping what I am going to do is, I am going to consider. For example, as an example scenario consider M equals 4, that is the size of the M point FFT that is I am going to consider M equals 4 and N equals 12, N equals 12 subcarriers, which means I have X 0 4 information symbols, X 0, X 1, X 2, X 3. I perform the M point FFT, which is essentially the 4 point FFT, these are X 0, X 1, X 2, X 3. So, these are the symbols that are now to be loaded on to the N 12 subcarriers. So, these 4 symbols need to be loaded on to 12, this 4 symbols need to be loaded on to the 12 subcarriers and this can be done as follows.

(Refer Slide Time: 22:32)



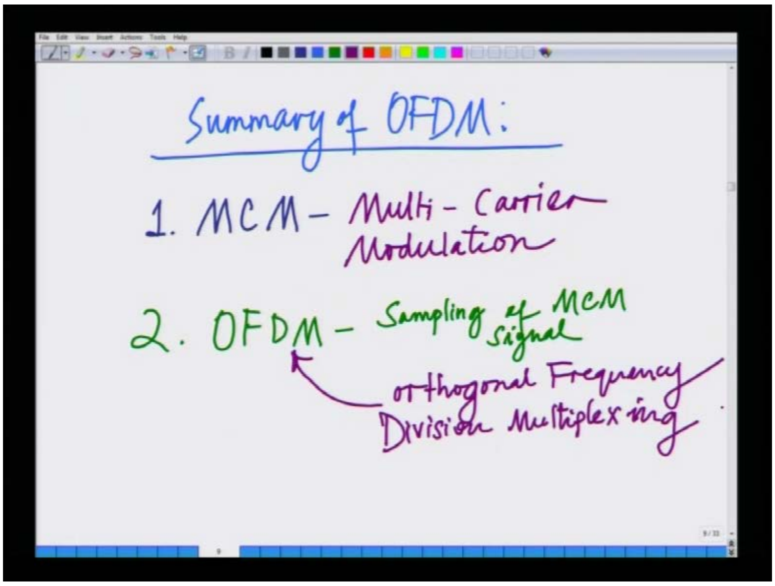
For instance, what can be do, one way to do this is so I have 12 subcarriers. So, how I am I going to do, so I have 12 subcarriers. I can load X zeros as follows. I can load X 0, 0, 0 X 1, 0, 0, X 2, 0, 0, X 3, 0, 0, so these are the 12 subcarriers, carriers. I am even look at this, I am interleaving the zeros with the symbols. So, these are I am interleaving zeros. This is turned as this is termed as interleaved FDMA FDMA or essentially IFDMA, all right? So, one way to load these 4 FFT symbols on to the 12 subcarriers is to interleave them with zeros. I have namely 1 symbol 2 zeros, 1 symbol 0 zeros, 1 symbol 2 zeros, 1 symbol 2 zeros and so on and now perform the N point IFFT. This is known as interleaved FDMA.

(Refer Slide Time: 24:23)



Another way another simply way as we all know is of course, to simply do 0 padding operation. That is written 2, 3, 4, 5. So, again I have 12 subcarriers. So, what I can do here is, I can load them on to the first four subcarriers and leave the rest of them 0. This is essentially 0 padding based subcarrier, mapping this is 0 padding based subcarrier mapping in SCFDMA and this in fact is known as LFDMA. This scheme is termed as LFDMA and in fact this is the scheme that is used in the uplink of the 3 g p p that is 4 generation standard LTE. This is used in employed in uplink of LT LTE, which is the fourth generation 3 g p p.

(Refer Slide Time: 26:28)

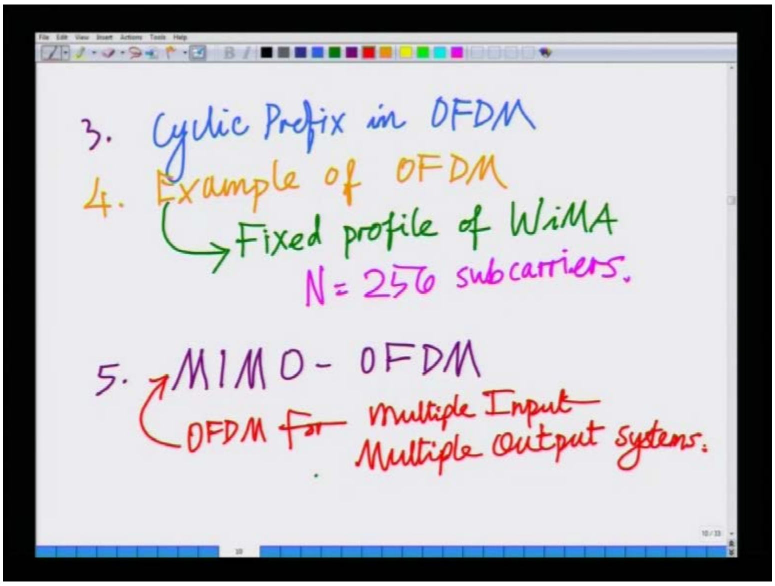


Hence, there are two techniques; one is interleave the 0 this is termed as IFDMA, the other is 2 0 pad, this is termed as LFDMA. In fact this is used in LTE, which is the fourth generation wireless communication standard. So, this brings us to the conclusion of section on OFDM. Hence, let us now summarize the different modules that we have seen in OFDM. Now, let us look at the summary of the OFDM modules that is summary on what we have seen in OFDM so far.

So, in OFDM starting with the first thing we have seen is the first thing we have seen is multi carrier modulation, which forms the basis for OFDM. So, we have started with multi carrier modulation, which forms the basis for OFDM. Second we saw OFDM itself, this leads to OFDM, which is results from the sampling of the MCM signal. This we said sampling of

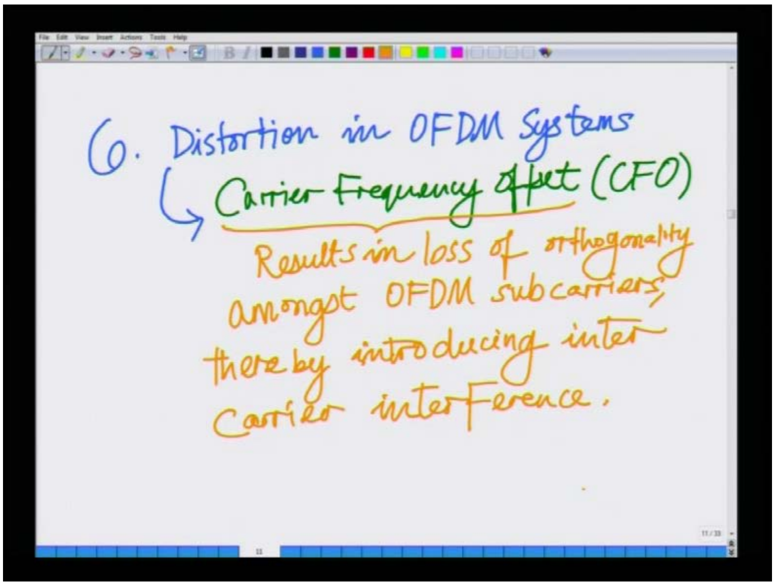
MCM signal, this is nothing but stands for orthogonal OFDM stands for orthogonal frequency division orthogonal frequency division multiplexing.

(Refer Slide Time: 28:03)



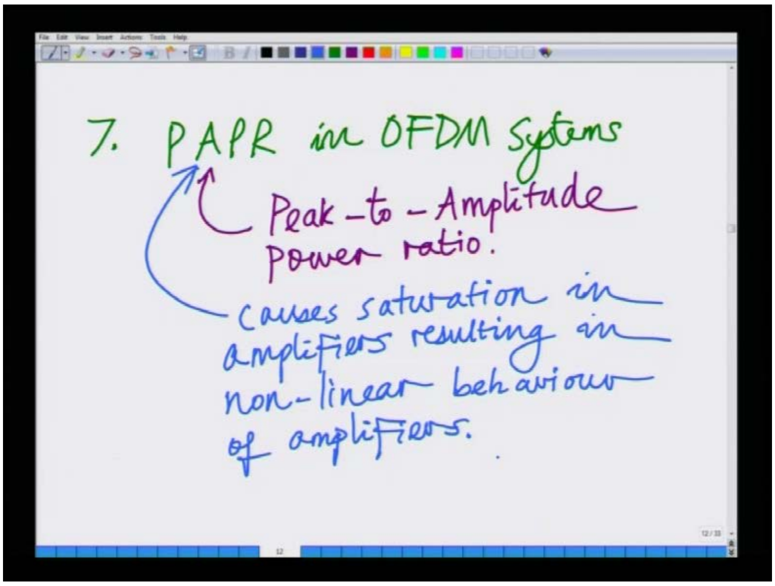
Then we looked at the concept of cyclic prefix we looked at the concept of CP or cyclic prefix. We also looked at an example a practical example of OFDM, this related to the fixed profile of wi max which is the 4 G wireless standard with 256 subcarriers. So, we looked at the fixed profile of wi max, this had N equals 256. This had N equals 256 subcarriers. Then we looked at an important aspect that is MIMO OFDM, which is essentially multiple input multiple output OFDM that is this is essentially OFDM OFDM for multiple input multiple output system. So, this is essentially OFDM for multiple input multiple output systems.

(Refer Slide Time: 29:45)



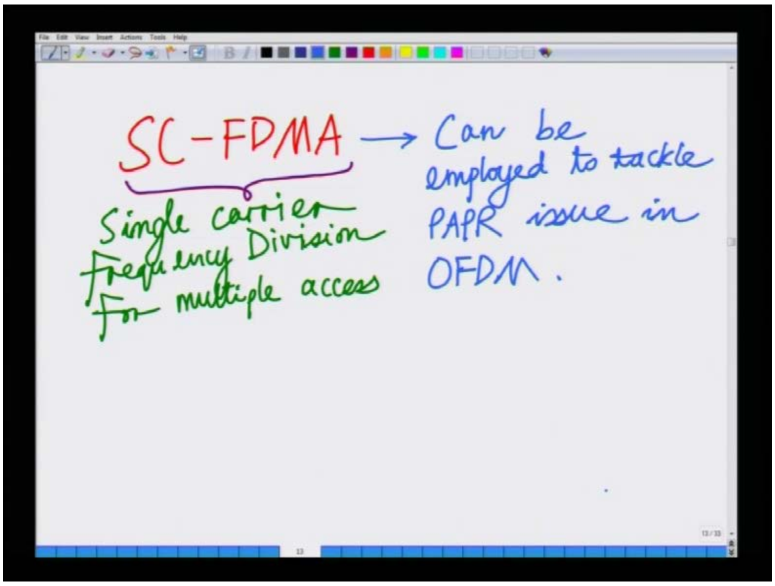
Then we looked at distortion in OFDM systems. We looked at distortion in OFDM systems, namely we looked at the problem of carrier frequency offset offset or CFO which arises in OFDM. This is serious problem we said because this results in loss of orthogonalilty amongst o f d m subcarriers there by introducing inter symbol interference inter carrier interference. There by introducing inter carrier interference.

(Refer Slide Time: 31:17)



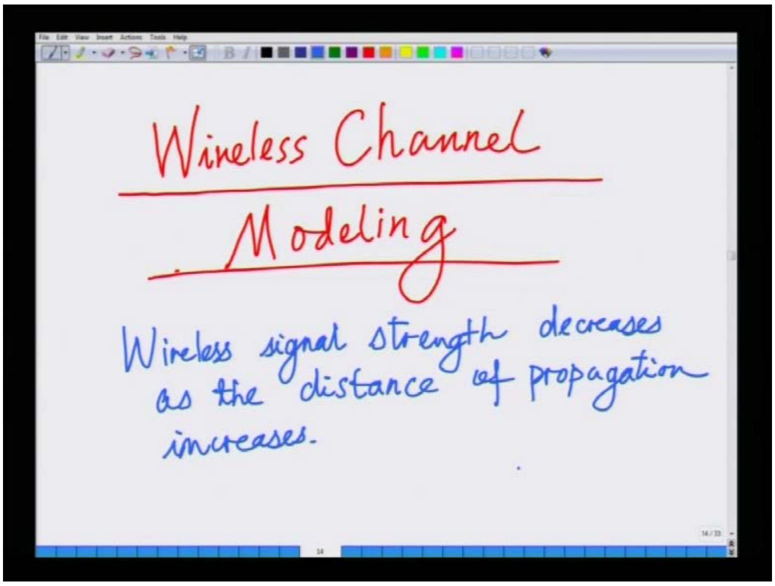
The next we said another important factor that needs to be considered in OFDM is the PAPR in OFDM systems were PAPR stands for peak to amplitude. PAPR stands for peak to amplitude power ratio in OFDM and this also we said causes saturation in amplifiers, causes saturation causes saturation in amplifiers resulting in non-linear behavior, resulting in non-linear behavior of amplifiers in the OFDMA systems. So, that is the problem of PAPR.

(Refer Slide Time: 32:41)



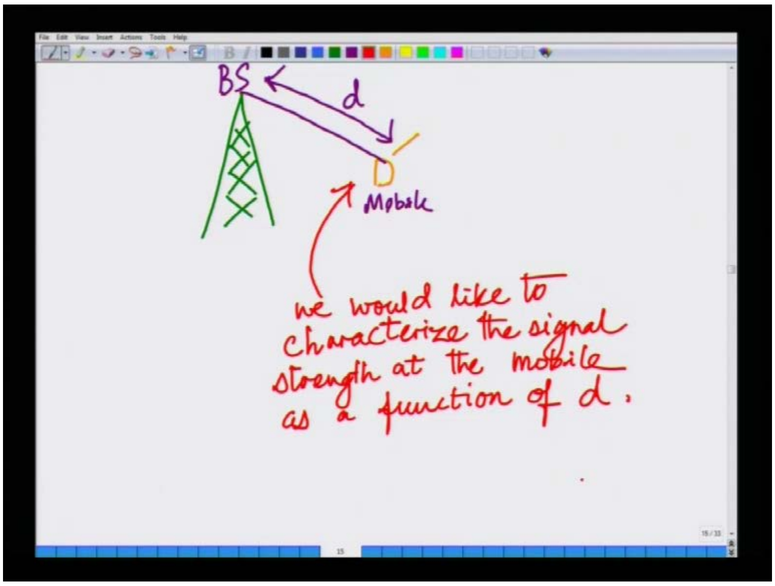
We said tackle the problem of PAPR we can use SCFDMA that is SCFDMA, which stands for single carrier this stands for single carrier frequency division for multiple access. This can be employed to tackle PAPR issue in OFDM, we said PA single carrier FDMA can be employed to address or can be employed essentially to tackle the problem of peak to amplitude power ratio. That is problem high that is the PAPR high peak to amplitude power ratio in OFDM systems. So, with that we come to a conclusion of the OFDM module and now we want to start a new module, which essentially leads to channel modeling in wireless systems.

(Refer Slide Time: 34:07)



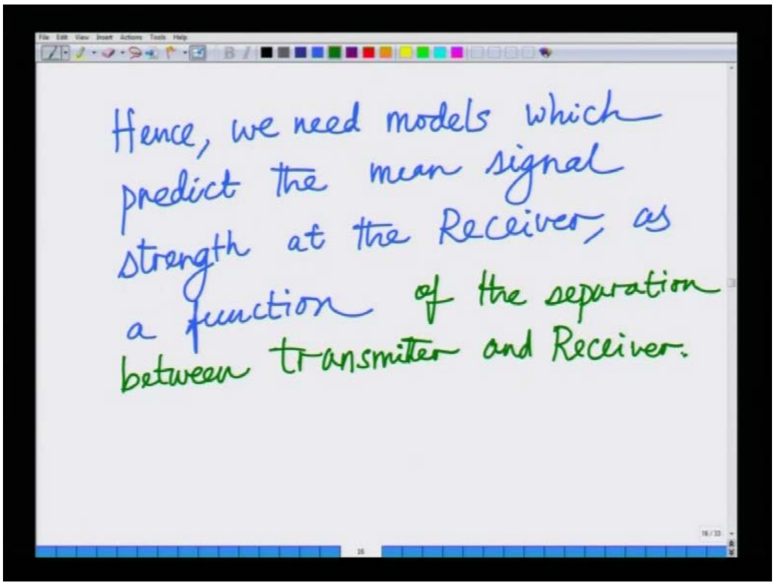
So, the next module we want to talk about or the next module we want to talk about is essentially wireless channel modeling. This is the next topic that we want to talk about and we want we all we know already from our basic knowledge of RF propagation that the wireless signals strength decreases with increasing distance. So, we know that wireless signal strength decreases as the distance of propagation. We know the wireless signal strength decreases as the propagation distance increases.

(Refer Slide Time: 35:21)



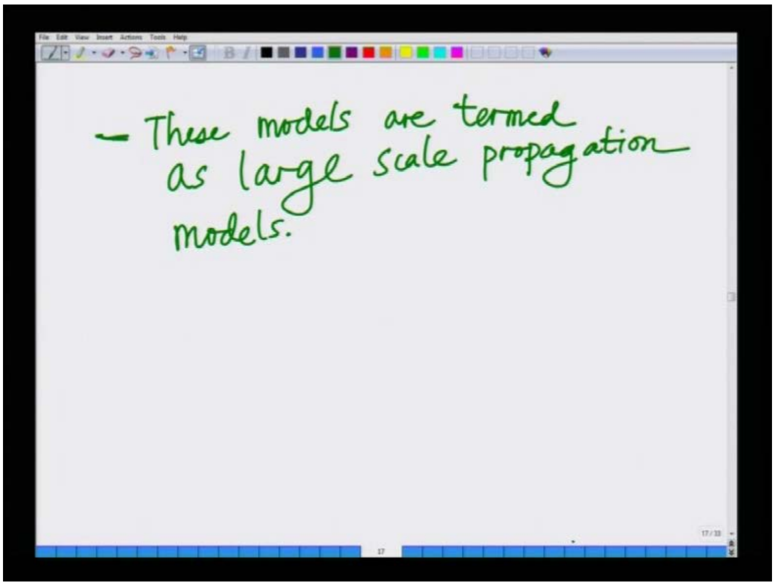
For instance we look at of base station and a mobile and we look at the distance d between the base station and the mobile. In fact we can also look at the straight line distance d between the base station and mobile. We would like to predict, we would like to find the signal strength required at the base station to receive a signal at the mobile at an intelligible signal at the mobile at a distance d. Hence, what we would like to do we would like to do characterize, like to characterize the signals at the mobile as we would like to characterize the signals strength at the mobile, as a function of d. This these since we need models which predict the mean signal strength as a function of the distance between the transmitter and receiver for essentially the design of a cellular system.

(Refer Slide Time: 36:48)



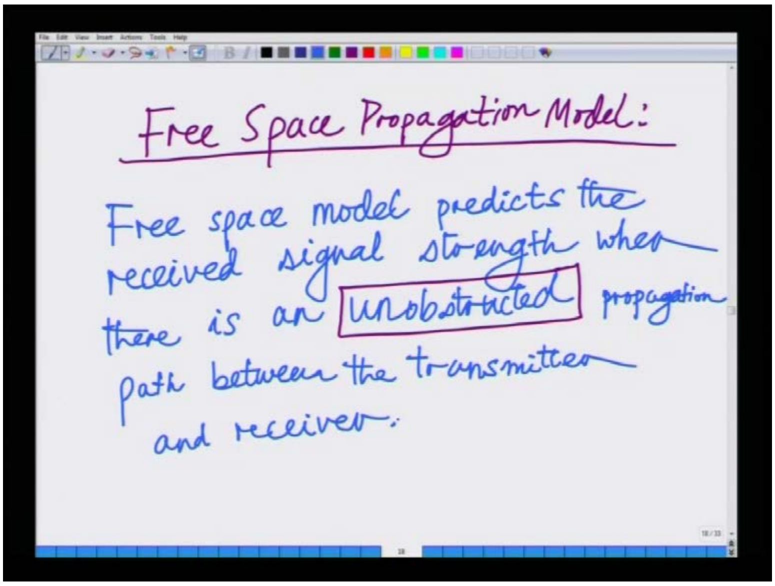
Hence, hence we need models which predict the mean signal strength which predict the mean signal strength at the receiver as a function of the separation between transmitter and receiver. Hence, we need essentially need what do you want to do is we want to build models, which can actually essentially characterize the signal strength at the receiver as the function of the separation between this transmitter, which is the base station and receiver. Same when the mobile is the transmitter and the base station is receiver, we need models which can characterize the signal strength. So, that we can characterize the transmit power. So, that we can characterize the received power and so on and these models are essentially termed as propagation models.

(Refer Slide Time: 38:35)



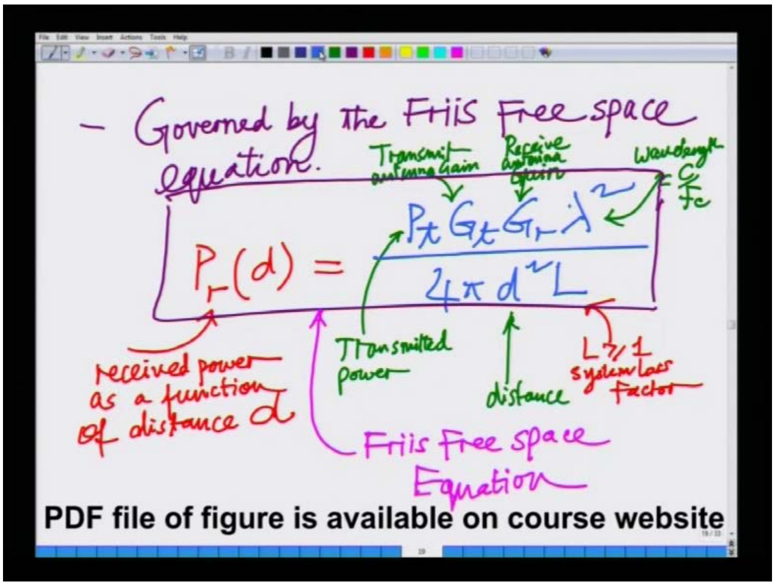
Hence, these models are termed as channel models or large scale propagation models these models. Models are termed as large scale propagation, these models are termed as large scale propagation model, we will start looking at some of these propagation models to characterize the received signal strength in a wireless communication system.

(Refer Slide Time: 39:18)



So, let us start with the basic model which is the free space propagation model. So, I want to start with the basic model which essentially the, which is the free space propagation model. The free space propagation model it predicts the receive signal strength when there is an unobstructed part within the between the transmitter and the receiver. So, this the free space model predicts the received signal strength when there is an un unobstructed. Remember this is the key which is essentially when there is an unobstructed path between, there is an unobstructed propagation part between the transmitter and the receiver. There is an unobstructed propagation path between the transmitter and the receiver.

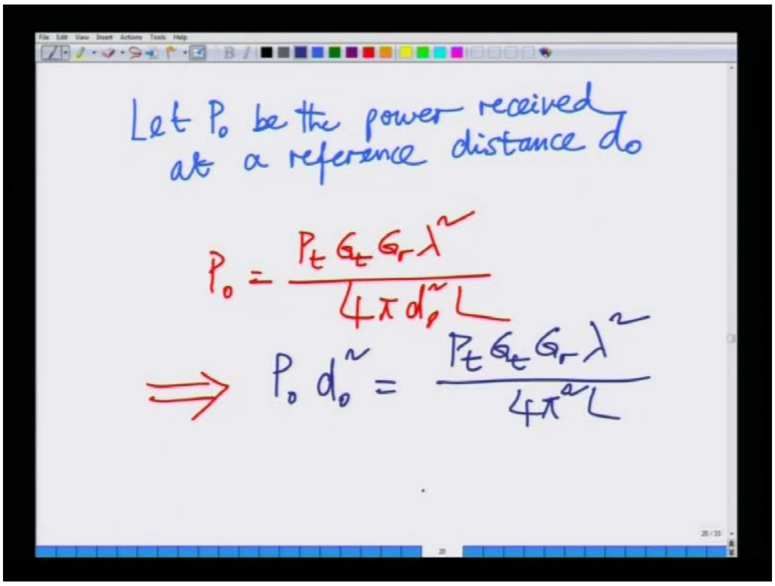
(Refer Slide Time: 40:53)



This is governed by the Friis free space equation. This is governed by the Friis free space equation where they received power as a function of d P r that is the received power as a function of distance d is given as P t G t G r lambda square divided by 4 pi d square l that is the received power P r as a function of d is given by P t G t G r lambda square divided by 4 pi d square L, where each of this quantities is defined as follows. P t is nothing but the transmitted, this is the transmitted power G t is a transmit antenna gain, G r is a receive antenna gain and lambda is nothing but the wavelength, this is the wavelength, which is equal to C over F c where F c is the carrier frequency and this d of course, d is the distance.

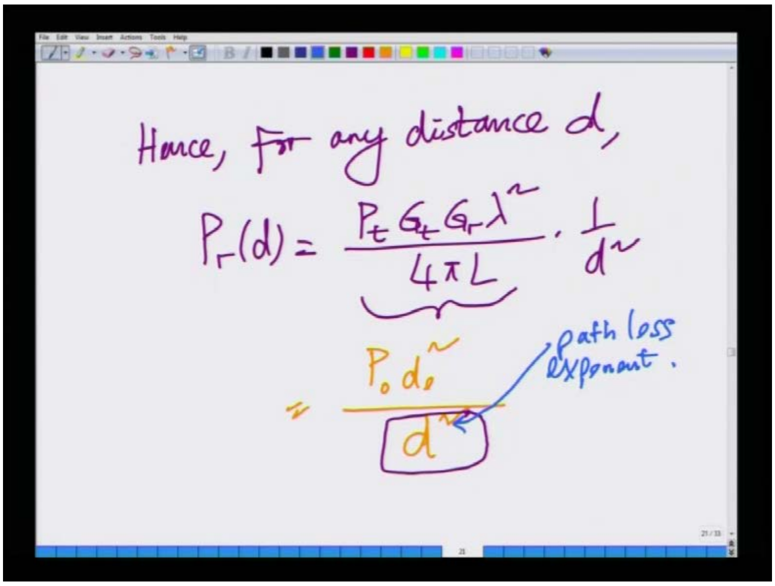
This L is the system, L greater than equal to 1, this is nothing but the system loss fact. That is why it gives giving by the transmit power times, the transmit antenna again times the receive antenna, again times lambda square where lambda is the wavelength divided by 4 pi d square where s is the distance and the system loss factor all right? So, this is essentially what we have as the expression. So, this is our expression that we have basically for this received power as a function this this is nothing but the Friis free space equation. Let me just write this again this is nothing but the, this is the Friis, this is nothing but the Friis. Free space equation.

(Refer Slide Time: 44:13)



Now, we can simplify this a full loss let us consider let P naught be the power received at reference distance d naught, let P naught be the power received at a reference distance d naught, then we have we have P naught equals P t G t G r lambda square divided by 4 pi d naught square L implies. If we consider P naught d naught square that is equal to P t G t G r lambda square by 4 pi square L that is equal to 4 pi square L.

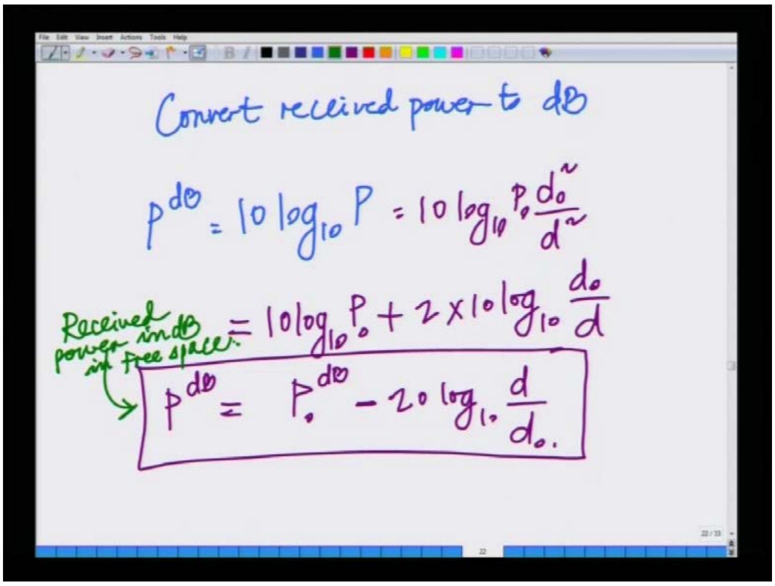
(Refer Slide Time: 45:17)



Hence, for any distance d, hence for any distance what we have is P received as a function of d equals P t G t G r lambda square divided by 4 4 pi 4 pi L into 1 over d square. This what we already saw is nothing but, p naught d naught square hence this is equal to this is equal to P naught d naught square by d square that is the power received at any distance d. Some constant which is P naught d naught square that is reference power P naught received at distance d naught divided by d square.

This factor actually d square is the most important that is it shows that the power decreases as the square of the distance. This factor 2 this power 2 is known as the path loss exponent. Shortly we are going to see how the path loss exponent differs its nominally. It is true, but path loss exponent in urban urban regions can be greater than to in fact it lies usually between 2 and 4 all right? Hence, one small last step which is we want to cover convert this received power in d B.

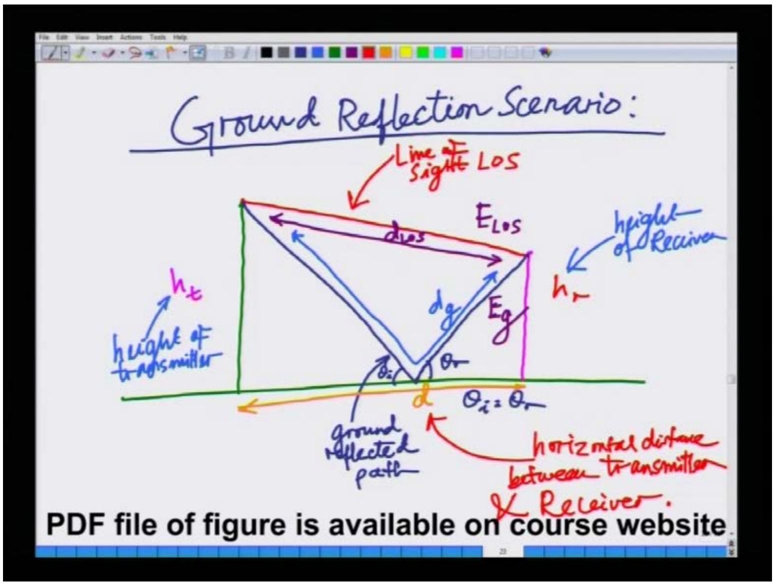
(Refer Slide Time: 46:57)



Convert received power to d d d B, we have P d B is nothing but 10 log 10 p, which is equal to 10 log 10 P naught d naught square divided by d square, which is essentially 10 log 10 P plus twice into 10 log 10 d naught by d, which is essentially P naught d B. There is reference power in d B minus 20 log 10 d by d naught. So, P in d B this is the free space received power received power in d B this is a received power in d B in free space. We saw that for free space path lot is is exponent is is true, is 2 for free space.

However, in cellular environments in urban cellular as defined by the first lecture, there is a dense clutter there is lot of scattering there is a lot of reflection. Hence, there is rarely free space propagation alright there might be a line of sight where there are also several reflected and scatter bath in such scenarios. We see that the path laws exponential can be greater than d square. In general the path loss exponent can be in between 2 and 4, we are going to see an example of this, for instance let us consider the ground wave deflection scenario.

(Refer Slide Time: 49:31)

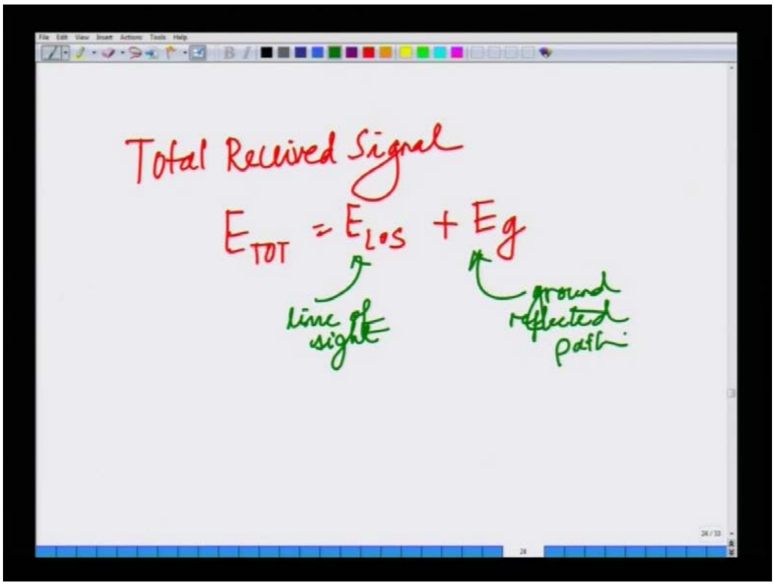


So, let us as an example to see how the path loss exponent can be greater than 2, let us consider a typical ground reflection. Let us consider a typical ground reflection scenario. The ground reflection scenario can be modeled as follows. I have a transmitter at a height t and I have a receiver at height h r, so h t is the height of the transmitter h r is the height of the receiver. Now, there is a direct path between the transmitter and the receiver. This is the line of sight or LOS path between the transmitter and receiver. There is as well also there is also another path which is a reflected path.

So, this path is essentially the ground reflected path such that the angle of incidence theta and angle of reflection are equal, angle of incidence and angle of reflection are equal. Let me call this distance as the line of sight distance and let me call this distance as the ground reflection distance. We can see the both these distances are different and we said h t, this is nothing but the height of transmitter. That is let us say something like height of base station in or cellular system and this is height of receiver that is length of the height of the person who is talking or may be who is on the building the height of the building and so on.

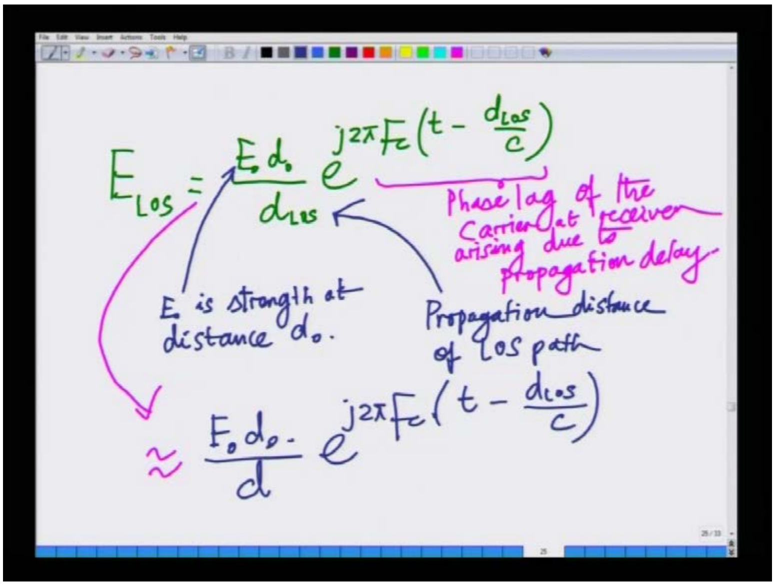
So, we have two paths now, we have one is the the LOS path. Let us say the field along the receiver of this path is ELOS and the field at this path let us say is E g, which is get coming from the ground reflected path. Further let us denote this distance horizontal distance between the transmitter and receiver by d, this is nothing but this is essentially horizontal distance between the transmitter. So, this is the horizontal distance between the transmitter and the receiver. So, that is what we currently have. Hence, what we observe is that we have two propagation paths that is one is the direct path one is the reflected path, once the line of statement is the reflected.

(Refer Slide Time: 53:03)



Hence, the total received signal is nothing but e total which is equal to E line of side plus E ground. This is again from the line of sight path and this is from the ground reflected. This is from the ladder sight path and the ground reflected path. Now, each signal E naught first for instance, let us look at the line of sight path that is some E naught

(Refer Slide Time: 53:52)



Let e naught be the reference strength at some distance d naught remember the power d k s by distance by d square in free space which implies the strength the signal strength d k s by a factor of d. Hence this is some e naught d naught by d and then there is going to be a in fact this is d LOS and there is going to be a face factor that is essentially arising because of the propagation distance. So, in this what we are seeing essentially that E naught E naught is strength or the field strength at distance d naught that is some constant d LOS is the propagation distance.

Remember this is the line of sight d LOS is the line of sight propagation distance or propagation distance of LOS path. This we are saying is the phase factor arising in the carrier due to the propagation, this is the phase lag of the carrier at receiver arising due to propagation delay. Now, what I am going to do is I am going to use an approximation. I am going to set this d LOS in the denominator as approximately equal to d.

Hence, I am going to use the approximation that this is approximately equal to E naught d naught divided by d E times j 2 pi F c t minus d LOS by c, where I have approximated d LOS that is the line of sight distance by the signal strength by d, because the major effect of the propagation distance is in the phase factor. The effect on the signal strength is not very significant. So, due to due to so because of shortage of time I have to end this lecture here and then again we are going to start from here and continue with this in the next lecture.

Thank you very much.