**Fundamentals of MIMO Wireless Communication**
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**Lecture – 07**
**Large Scale Propagation Models Path Loss and Shadowing**

Welcome to the course on fundamentals of MIMO wireless communications and now, we are studying the large scale propagation module. What we have seen in the previous lecture is the path loss or the signal accumulation due to separation between transmitter and receiver. What we have said is the received signal strength at the receiver of the average received signal strength of the receiver is inversely proportional to the separation distance raised to the power of certain exponent and that is what is the last expression as we have seen.

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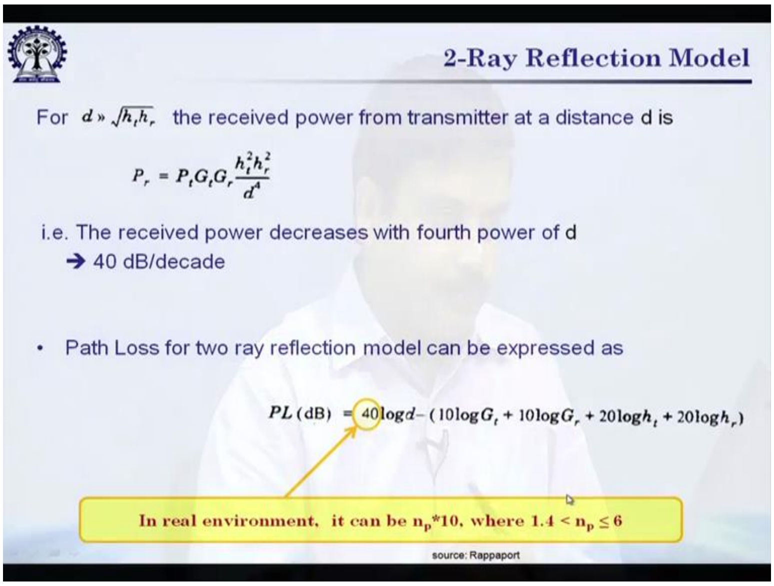


So, what we were seeing in the previous expression is for the 2 ray model. Where we had seen the path loss exponent is d raised to the power of 4 because when, we do in the dB scale that is n log of d n log of d raised to the power of 4 and that 4 has come here as forty log d. What we also said is in practical environments these numbers instead of being such a nice numbers as 2 and 4 as being 2 and 4 these numbers can be any other numbers yeah.

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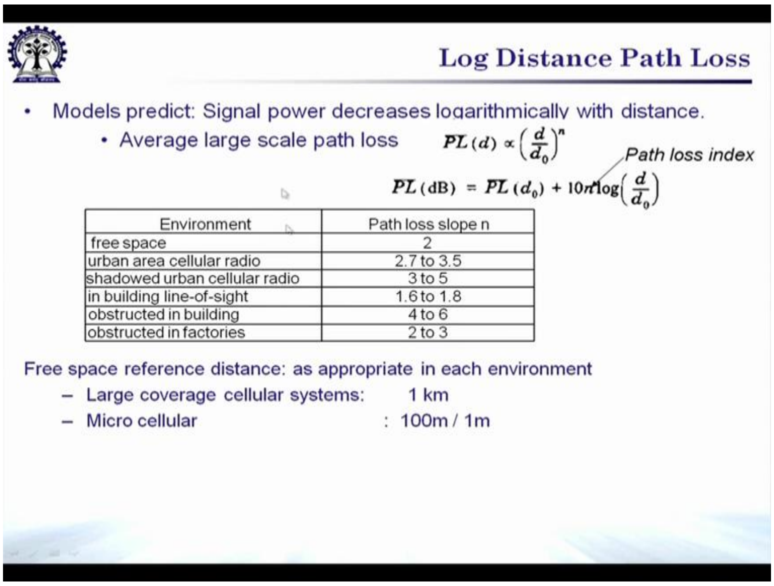


So, as we continue to look at these particular expressions what we see is as we have just described path loss at a distance d is inversely proportional to d raised to the power of n and of course, normalized by d 0 and hence we could write p l in in decibels as path loss at d 0 that is the closing distance and what we have seen is 1 could measure the p r at received d 0 that is deceived signal strength at d 0 and plus the 10 n p that is the path loss exponent of log of d by d 0.

What we see below is for specific environments how does this path loss slope or this exponent vary for free space we have already seen this path exponent is 2. Whereas, if you take a typical urban cellular radio environment it varies from 2.7 to 3.5, these as the numbers indicate there is a range of variation these numbers are not really fixed they have to be measured and through curve fitting with these formulas these numbers are to be come up with these numbers would also depend upon the frequency if the shadowed urban cellular region; that means, when there is lot of obstruction between the transmitter and the receiver you get numbers in the range of 3 to 5.

In building line of sight; that means, when you inside a building between 1.6 to 1.8, So, as these numbers are less than 2 this indicates kind of wave guide effect typically like a corridor where there is like signals are guided towards 1 direction and losses less than 2.

Obstructed building; that means, inside a building, where there is obstruction. For example, separation walls partitions rafts almirahs many other things as typically happens inside a building your path loss exponent would go between 4 and 6 and in factories it could range between 2 and 3 and free space reference distance as was mentioned earlier also it in the large coverage it could be 1 kilometers in small coverage areas it could be 100 meters to 1 meter this would also depend upon the wave length of operation as well as the size of the antenna.

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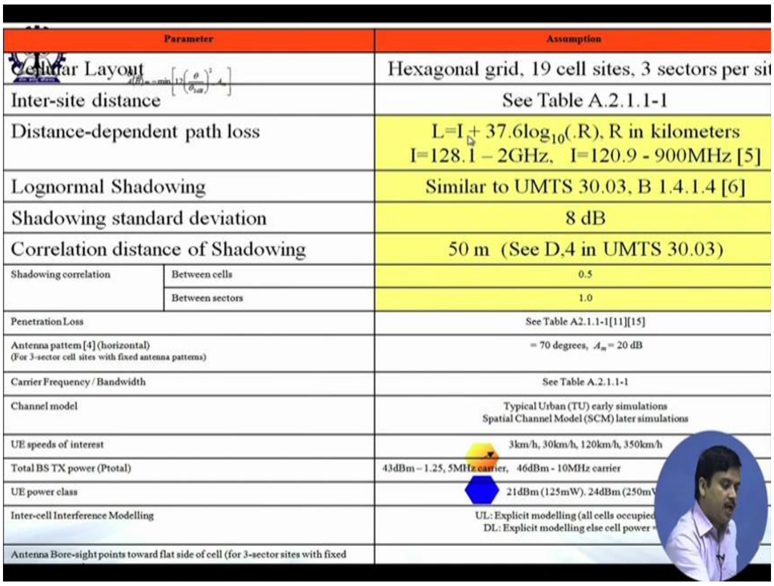


This particular slide shows the path loss expression as given by 3 g p p which is again very practical model for measurement. So, what we see if we try to read this expression it is showing distance dependent path loss. So, this is the distance dependent path loss expression which we are seeing out of many other parameters. So, l which is the loss parameter is indicated by I a particular variable plus thirty 7.6 log base 10 of r where r is in kilometers.

Now, we have to read this very, very carefully and should not make mistakes typically this d as we were mentioning earlier in such an expression is in meters. Whereas, in this particular expression it is given in kilometers, so, if the separation distance is 100 meters we have to write 0.1 in this particular case and as can be read from this from this particular value the path loss exponent would be 3.76 because 3.76 multiplied by 10 would give thirty 7.6 the first part which is I is described below as 1 100, 20, 8.1 in the 2 gigahertz band then, if you change the frequency to nine 100 mega hertz band 1 would have to use 100 and 20.9 because what we have seen in the free space propagation model the received signal strength is dependent upon the wave length or the frequency of operation.

In these models everything has been encapsulated so; that means, there is no antenna gain reflected I captures the effect of frequency and all possible losses at that particular frequency and r is the separation distance. So, once again what we can see the distance dependent path loss what we are encountering over and over again is the path and distance. So, we would like these expressions to be dependent only on distance as much as possible and all other parameters to be captured inside the model. So, that it is not visible any more to make the models as simple as possible.

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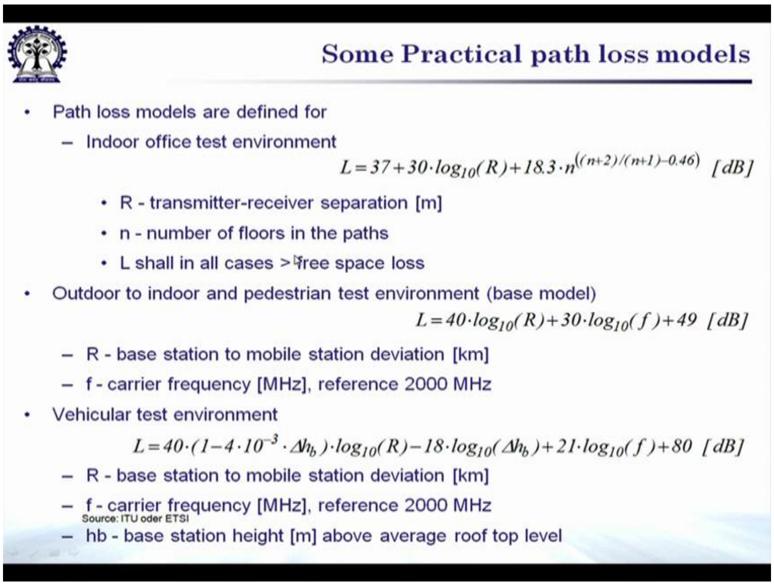


If we move down further and try to look at some other models which are known for example, indoor office test environment it looks more complicated when there is a fixed loss which is thirty 7 in dB and the path loss exponent does appears in this kind of 3 because 3 multiplied by 10 n is the number of floors in the path. So, basically if the transmitter is in the first floor and the receiver is in the second floor. So, there would be value of 1 for n l in all cases would be greater than free space losses so; that means, these are this loss that is present over here is of course; much, much greater than free space loss. So, this is a complicated formula which is for indoor office based environment.

If we move on to the next 1, which is like outdoor indoor pedestrian test environment model there these losses or these loss expression again in dB. It is mentioned it is in dB would be given by this particular expression where, we can see path loss exponent is a kind of 4 and there is 4 times 10 is 40 log based n of r plus 30 times log base 10 of f, this particular model captures the frequency of operation plus there are fixed losses which could be due to antenna and coupling and many other.

If we go to the vehicular test environment we also include the base station antenna h8above the roof top level and the frequency of operations. So, there are a various different models, but what is common in all of these models is r; that means, a separation distance between the transmitter and the receiver. So, in this particular model r is in meter in this particular model r is in kilometers and so on. So we have to be very, very careful with these particular models.

Now with these we move on to the discussion where we are not limited just to path loss now we move in to the next part of path propagation model; that means, shadowing.

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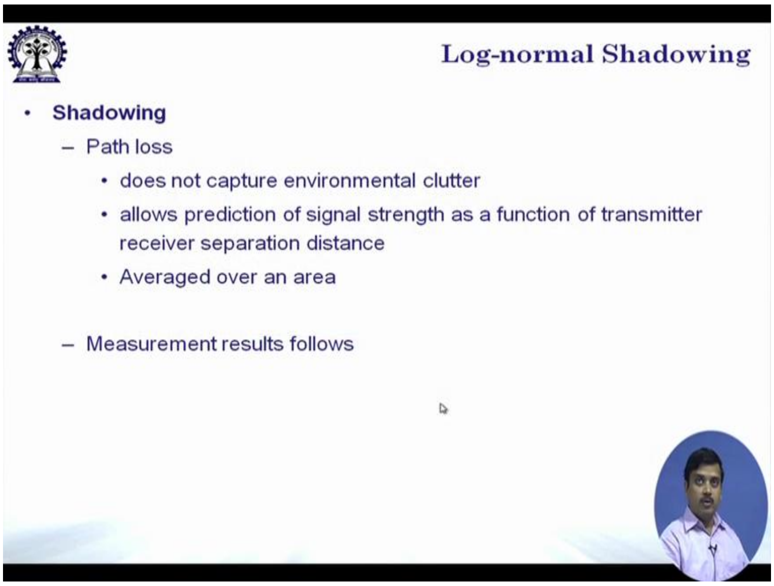


So, what why do we need shadowing we need shadowing because the path loss model as we were seeing it does not capture the environment clutter this sentence is partially true because we again draw the transmitter and we will draw the receiver.

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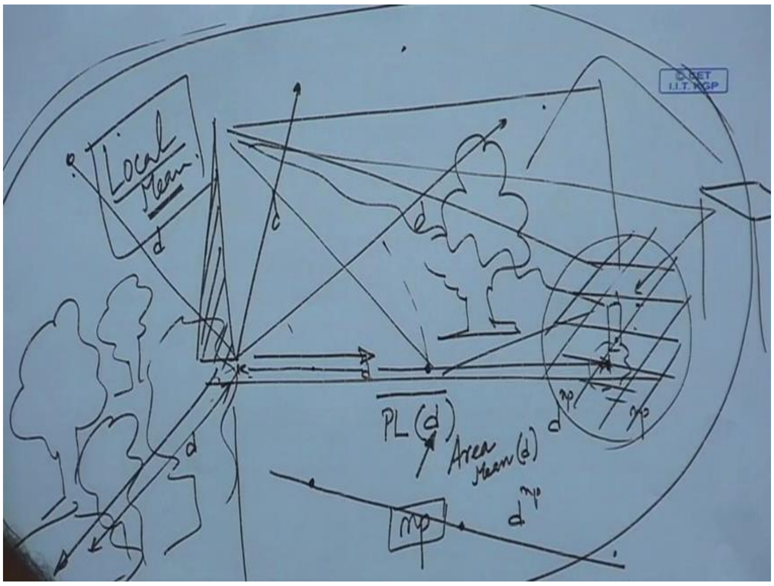


So, first let us take a scenario where there is only 1 hill; that means the hilly region. So, there would 1 line of sight possibly 1 reflected path and from the ground and 1 from the clock. So, this particular scenario will create a particular exponent of d, now if we move beyond and consider a situation where there is lot of buildings around there could be lot of trees in the obstruction path and so on and so forth. So, there would be things would come in they would be reflected definitely the value of n p would be different and that is kind of captured in the path loss model. Now whereas, if we take the same scenario into account and instead of proceeding in this direction, if we start proceeding in this direction we might encounter a different situation; for example, there could be lot of trees around there could be a water body and there could be lot of more buildings around the whole propagation environment here is different from the propagation environment on here however, we are talking of the same radiator.

So, in this big area if we look at this and we are trying to capture the propagation effects of the model what would we like to see a single value of n p in this whole area this is very, very important and the received signal strength as a separation between the transmitter and the receiver as you were seeing is given as p l of d or p l of r. Now when, it is given as p l of d; that means, what we are concerned is with path loss as a function of separation distance between the transmitter and the receiver.

This distance could be in this direction or it could be in this direction it could also be in other direction or any other direction in this area. So, if we have to capture these whole areas, with 1 single value of n p. We would not be able to capture the local variations as could happen in different directions. So, what is typically done is for path loss parameterization. We would go to a certain distance d do lots of readings over here take the value and use and store the average. Then we would go to another direction distance d take the value and go and do the similar thing across the whole area in different directions and what we get is the average path loss as a function of d and it is also known as d area mean as a separation distance function of separation distance d.

However, if we have to do a prediction of signal strength being above a certain threshold what we need to do or what we need to capture is local variations in these different directions clearly in this particular example, whatever we see in this direction is not a similar propagation environment in this direction.

So, we would like to use the path loss model for an average prediction of signal strength in a large area whereas, we would also like to capture the fluctuations which would indicate the local mean. So, this local mean which is the variation of signal strength in a particular direction. However, in the same areas is covered under the model by shadowing. So, as we move further what we need to look at is certain measurement result.

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What I will show you is a geographic map of a region this is belonging to IIT Kharagpur, we have done some measurement campaign over here. So, this red dot as indicates we have taken average readings, we have moved straight down this line there is transmitter located in this in this region. So, we are as if going away from the transmitter taken readings as a function of distance. So, we keep on doing it. So, basically going back to our figure here once we do it for one distance we would repeat the same exercise for another distance across this we repeat the same exercise at another distance. So, end result what we get is as we increase the separation distance at this separation distance there is a certain received signal strength average across the region.

I move further down I have done several readings in this area I get another average reading as I mover further down my distance has increased at that distance I take average reading across the whole area and I get the average received signal strength and what I get is the average received signal strength function of distance and the slope of d is indicated by n p.

So, based on that what we have done is we have taken one typical example, we have taken readings at 1 point at another point at another point. So, we are increasing the separation distance and we have calculated this distance of separation from the transmitter to the measuring points and we kept on moving in the straight line you can you can see the field here and as we moved down the field is here. So, we are moving almost in a straight line nearly a straight line and this is the edge of the previous picture. So, it is move straight down and we have measured signal strength up to this point.

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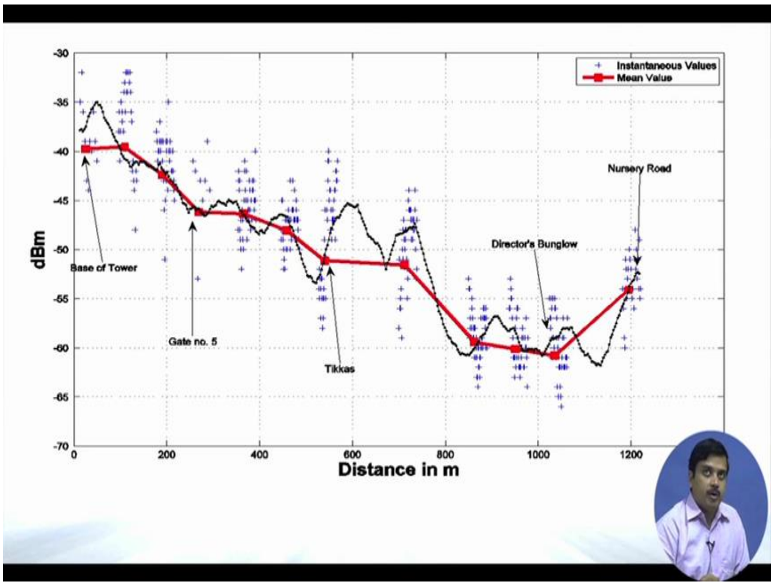


Then the plotted the result at the average received signal strength is as indicated by this red line. So, if it was only path loss in nature we would have expected a straight line in this direction with a particular slope; however, what we have received is fluctuations where signal strength goes down and then again goes up it could go again go out go down, but on an average there is decrease across distance, but to keep it to this local fluctuations as we have seen we need to improve upon the model which we have discussed till now.

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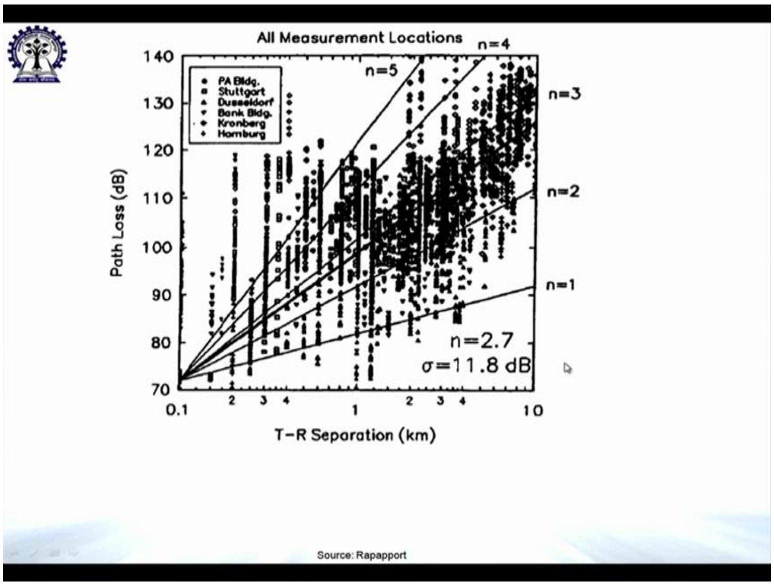

Now, this is alt is again from if you open the book you will find this particular figure in the book which represents path loss transmitted receiver separation is a function of distance and path loss in dB and these are like different values of exponent. So, even if there is like a path loss for a particular value of n p has given there are fluctuations about that particular slope. So, we have to find the mechanism in order to capture this model. So, that we are able to predict the received signal strength at a separation distance between the transmitter and receiver and not just look at the area average received signal strength.

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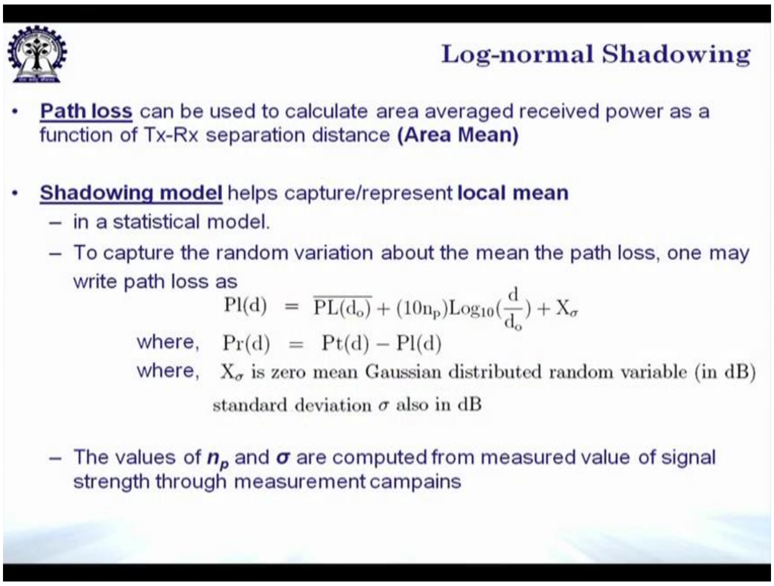


So, to improve the model over path loss the path loss as said is the area mean the shadowing model which is the local mean the received or the path loss can be written as path loss at d 0; that means, at the closing reference point d 0 plus n p 10 times n p n p would be would be the path loss exponent plus log raise 10 of d divided by d0 because d0 is known plus there is some x sigma this is a typical notation x sigma where, the received signal strength is p t at distance d minus path loss. So, with these 2 formulas you would be able to calculate the received signal strength at a distance d.

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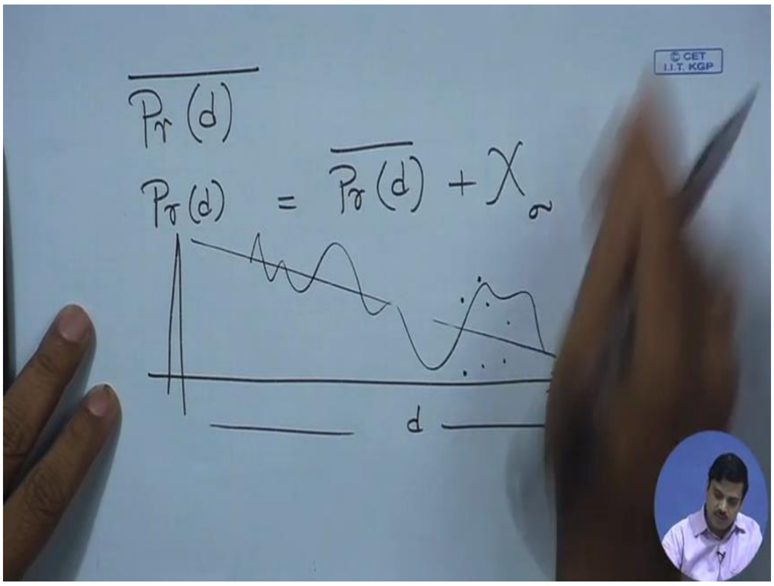

If we compare this particular expression with the 1 that we had done before what we would write for the previous expression is p r d and a bar on top is basically; what we would have from path loss only indicating the area mean right? Whereas, when we write p r d we mean at a distance d probably at a particular location what is the received signal strength.

Now, this you could also say is like the path loss or the received signal strength at d plus there is some random fluctuation beyond the average. Now this random fluctuation x sigma has been found from measurements to match a Gaussian distributed random variable in the dB domain so; that means, when the received signal strength is measured in decibels under such conditions the sigma follows a Gaussian distribution and this sigma which is indicated below x sometimes it is also referred to as pi is the standard deviation of this Gaussian random variable and also given in dB.

If the values of n p and sigma are actually computed from measured values through lots of measurement campaigns 1 of the typical measurement experiment that could be done, is what I have shown you in these extensive amounts of measurements from which these values of n p and sigma can be calculated if, we look at typical propagation models what we would find is if there is path loss on the on the y axis and separation distance between the transmitter and receiver there would be a certain slope which is found by the n p or the area mean of received signal strength and this is follows the power law with a factor.

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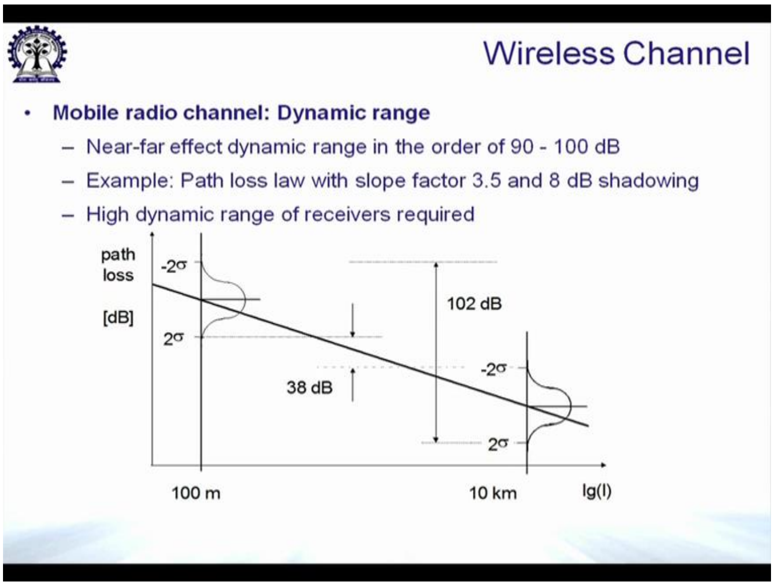


Let us say 3.5 in this particular example and if, we take these the shadowing which is the random component and the sigma that we have just described is this particular sigma. So, what we have assumed over there is np is 3.5 and this x sigma by sigma which is Gaussian distributed in dB domain has the value of a standard deviation around 8 dB as has been shown.

So, this is what we are going to get. So, this will result in further fluctuation of signal strength; that means, when we are close to the base station you would get fluctuations beyond this where, the maximum received signal strength would go even beyond predicted by the average because of the random fluctuation. If you see this model there is random fluctuation to support this we have, if you look at this data. So, signal strength can actually go above you will see it did not decrease monotonically it can go above and if this is the average slope as pointed by the cursor it could below the average. So, there is fluctuation above and below the average and this is a 0 mean. So, it means the mean is predicted by this part is a mean a mean path loss about the mean there is fluctuation on the positive side there is fluctuation on the negative side. So, this fluctuation in the positive side in the path loss model there is fluctuation of received signal strength in the negative side and vice-versa between the path loss model and the received signal strength.

So; that means, if we have the model here when you are at this are the very large distance from the base station a similarly signal strength is going to fluctuate both above the average path loss and below the average path loss. So, what you will find is that the received signal strength would be fluctuating greatly. So, this shadowing effectively increases the dynamic range of the received signal thereby posing even a bigger challenge for a transmitter receiver design for such wireless communication systems; that means, the receivers would require a much higher dynamic range to operate there are many, many mechanisms to take control of this which are typically studied in subject of mobile communications.

So, now if we look at the similar model from 3 g p p as we have seen in the previous lecture again we look at the same model we did not highlight some parts of this model which we will now, highlight as you seen below this l loss is have been this I plus 37.6 which is 3.76 multiplied by 10 log based 10 of r I of 2 Giga hertz is 100 and 28 and I for nine 100 mega hertz is almost 100 and 21. So, this particular model we have seen now this model is improved by giving the description about shadowing standard deviation which is given by 8 db. So, what you see is this path loss model is further improved or qualified by giving information about the standard deviation of shadowing which is 8 dB as in this particular model there are many more modules to shadowing also, but this is the minimum thing which we should consider in our calculations of predicting received signal strength.

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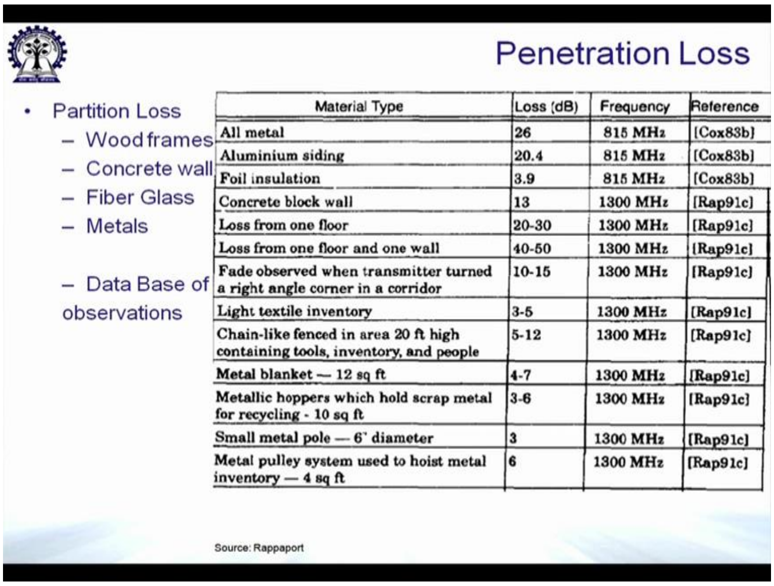


| Material Type | Loss (dB) | Frequency | Reference |
|---|---|---|---|
| All metal | 26 | 815 MHz | [Cox83b] |
| Aluminium siding | 20.4 | 815 MHz | [Cox83b] |
| Foil insulation | 3.9 | 815 MHz | [Cox83b] |
| Concrete block wall | 13 | 1300 MHz | [Rap91c] |
| Loss from one floor | 20-30 | 1300 MHz | [Rap91c] |
| Loss from one floor and one wall | 40-50 | 1300 MHz | [Rap91c] |
| Fade observed when transmitter turned a right angle corner in a corridor | 10-15 | 1300 MHz | [Rap91c] |
| Light textile inventory | 3-5 | 1300 MHz | [Rap91c] |
| Chain-like fenced in area 20 ft high containing tools, inventory, and people | 5-12 | 1300 MHz | [Rap91c] |
| Metal blanket — 12 sq ft | 4-7 | 1300 MHz | [Rap91c] |
| Metallic hoppers which hold scrap metal for recycling - 10 sq ft | 3-6 | 1300 MHz | [Rap91c] |
| Small metal pole — 6" diameter | 3 | 1300 MHz | [Rap91c] |
| Metal pulley system used to hoist metal inventory — 4 sq ft | 6 | 1300 MHz | [Rap91c] |

Now, these few slides are again taken from the numbers as given in the book by Rappaport, you will find similar numbers in other books. Of course, for different scenarios this is very specific to the measurement campaign which Rappaport has been reporting in many of his papers and many of the papers from other references as well some of the things, we will take from this like a metals around at the frequency of 8, 100 mega hertz have a loss around 20, 6 dB and if you look at the light textile inventory it has a loss of around 3 to 5 dB and if you look at some other situations there would be loss of around 10 to 15 dB plus some 1 floor and 1 wall is around 20 to 50 db. So, what do you see is when there are obstructions between the transmitter and receiver there is attenuation which is varies depending upon the type of obstruction and the frequency of operations.

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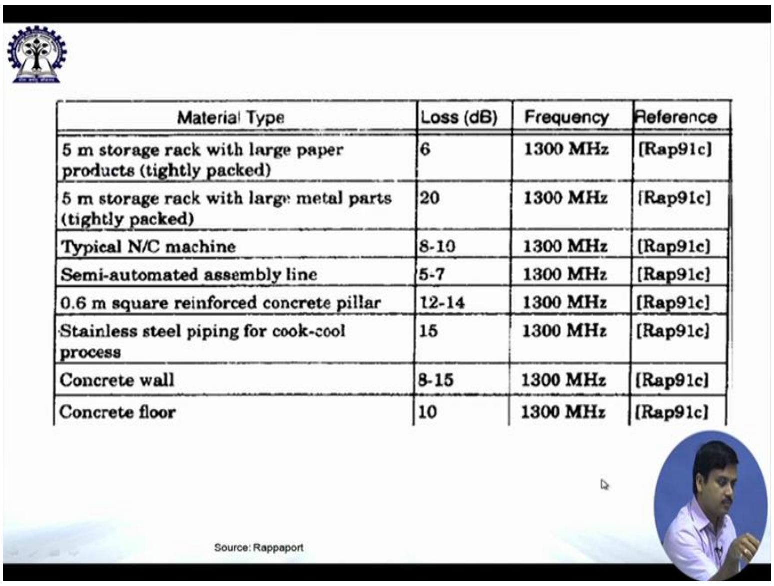

| Material Type | Loss (dB) | Frequency | Reference |
|---|---|---|---|
| 5 m storage rack with large paper products (tightly packed) | 6 | 1300 MHz | [Rap91c] |
| 5 m storage rack with large metal parts (tightly packed) | 20 | 1300 MHz | [Rap91c] |
| Typical N/C machine | 8-10 | 1300 MHz | [Rap91c] |
| Semi-automated assembly line | 5-7 | 1300 MHz | [Rap91c] |
| 0.6 m square reinforced concrete pillar | 12-14 | 1300 MHz | [Rap91c] |
| Stainless steel piping for cook-cool process | 15 | 1300 MHz | [Rap91c] |
| Concrete wall | 8-15 | 1300 MHz | [Rap91c] |
| Concrete floor | 10 | 1300 MHz | [Rap91c] |



If we move beyond to certain other references again from the Rappaport book, what we find is if there is a 5 meter storage rack with large paper products it is loss of around 6 dB whereas, with metal parts loss around 20 dB and so on and so forth.

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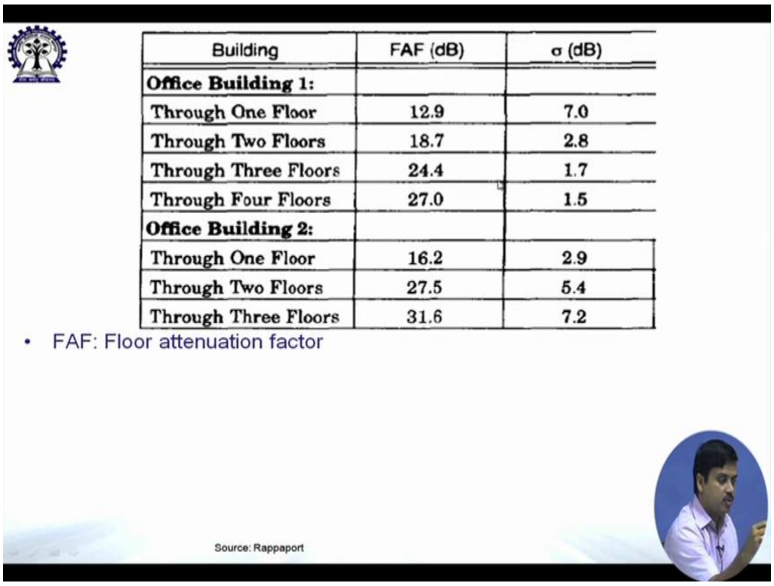

| Building | FAF (dB) | σ (dB) |
|---|---|---|
| **Office Building 1:** | | |
| Through One Floor | 12.9 | 7.0 |
| Through Two Floors | 18.7 | 2.8 |
| Through Three Floors | 24.4 | 1.7 |
| Through Four Floors | 27.0 | 1.5 |
| **Office Building 2:** | | |
| Through One Floor | 16.2 | 2.9 |
| Through Two Floors | 27.5 | 5.4 |
| Through Three Floors | 31.6 | 7.2 |



There is this floor attenuation factor when, it is through 1 floor it is around 12 dB 2 floors it is around 18 dB 4 floors 20 around dB and so on and so forth.

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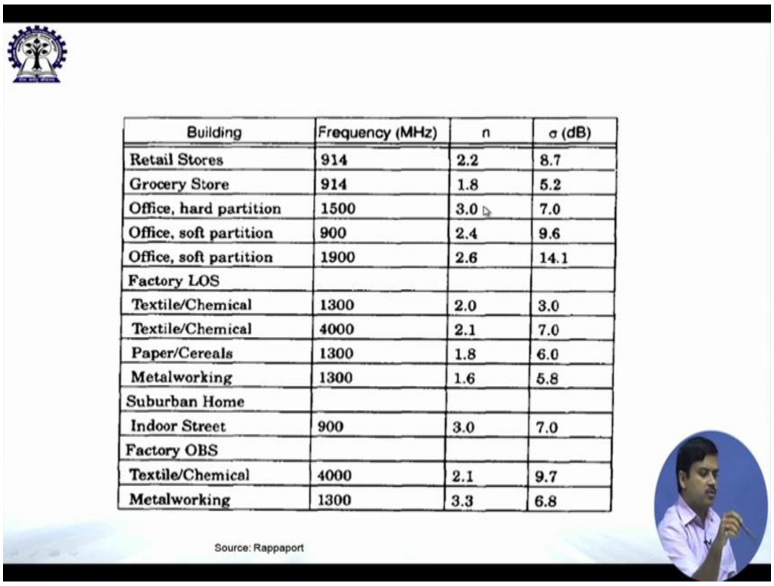

| Building | Frequency (MHz) | n | σ (dB) |
|---|---|---|---|
| Retail Stores | 914 | 2.2 | 8.7 |
| Grocery Store | 914 | 1.8 | 5.2 |
| Office, hard partition | 1500 | 3.0 | 7.0 |
| Office, soft partition | 900 | 2.4 | 9.6 |
| Office, soft partition | 1900 | 2.6 | 14.1 |
| Factory LOS | | | |
| Textile/Chemical | 1300 | 2.0 | 3.0 |
| Textile/Chemical | 4000 | 2.1 | 7.0 |
| Paper/Cereals | 1300 | 1.8 | 6.0 |
| Metalworking | 1300 | 1.6 | 5.8 |
| Suburban Home | | | |
| Indoor Street | 900 | 3.0 | 7.0 |
| Factory OBS | | | |
| Textile/Chemical | 4000 | 2.1 | 9.7 |
| Metalworking | 1300 | 3.3 | 6.8 |



So, what here is in this particular slide again taken from Rappaport as given in the particular book? What we will find is at different frequencies different values of path loss exponent and standard deviation are reported, for example, in a typical retail store path loss exponent of 1.2.2 with shadowing standard deviation of 8.7.

Now, with these 2 parameters specified we complete the model through which we can generate samples of received signal strength which would statistically meet the performance or the measured values has been obtained in the grocery store. What we can see is the values would decrease to 1.8 of course, it depends upon the type of store and the type of locality and the type of things that are kept what we see is 1 of the highest is in metal working location, where it is 3.3 and there is also around there in office with hard partition and the values of sigma having a range of around up to 14 it has low value of around 3. So, what do you see that sigma is also having lot of variations np is also having lot of variations.

So, when we are supposed to solve a particular problem we will be expecting these numbers to be first found out which are modeled and experiments once these numbers are available then we can do coverage probability analysis.

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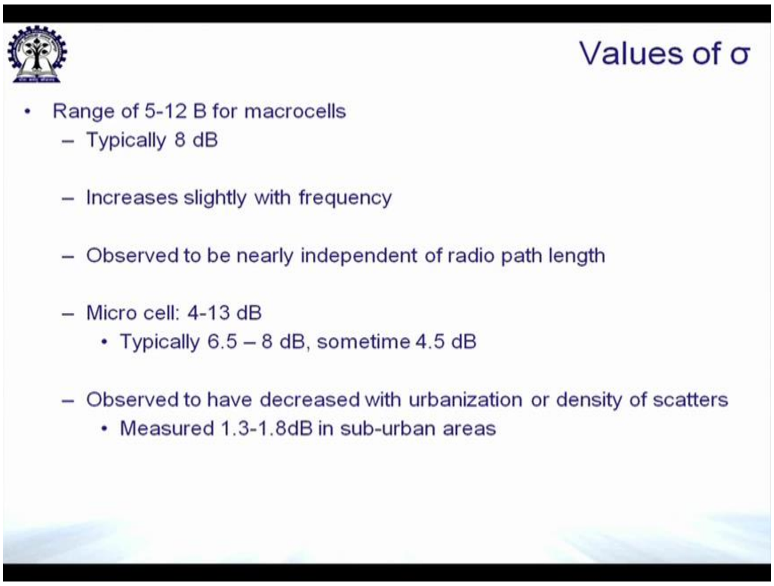


So, to summaries we can see that the range of sigma is in is within like 5 to 12 dB and typically around 8 dB it increases slightly with frequency as has been reported by some observations and it is a nearly independent of the radio path; that means, it does not depend upon the separation between the transmitter and the receiver it is for micro cells it has been found to be around 14 to 13 dB typically in the range of again 6 to 8 and sometimes going to 4.5 dB and it has also been found to decrease with urbanization and density of scattering there is too much then there is also it is been found to decrease to 3.1.3 to 1.8.

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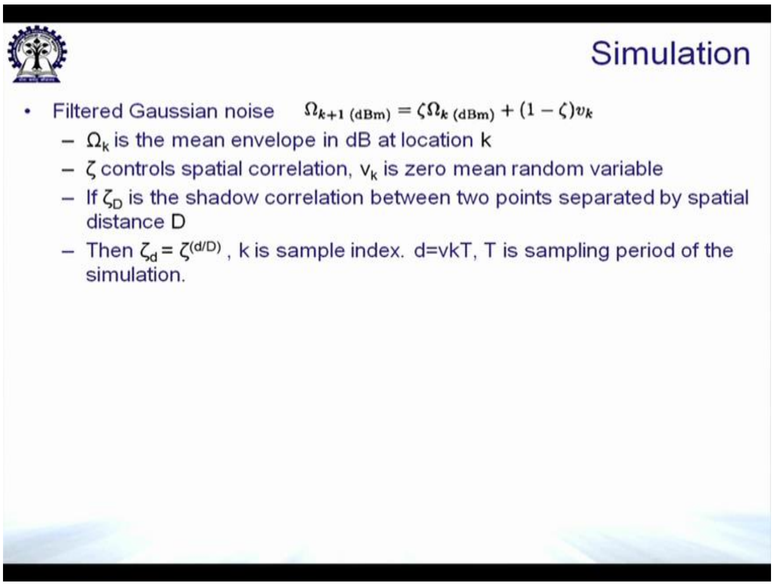


There is also a method to simulate these shadowing values which would be added to this path loss exponent. So, basically what we mean by this is in this formula, how we do we get these values of x sigma now this x sigma are basically Gaussian random variables with 0 mean and a particular value of standard deviation. So, these values are to be generated following this distribution.

Now, what we can remember is that as we have the separation distance between the transmitter and receiver is given by d there is path loss, there is shadowing. How this shadowing is typically correlated; that means we do not find abrupt fluctuations of average received signal strength; that means, if we take this particular figure. Which we have drawn in this region in this region, you would find slow fluctuation of the local mean we would not find a sudden high of around 10 dB and within the next 1 meter another dB because, these are all average this is the local mean as has been see this is still a mean, mean means averaging over a small area; that means, if the readings are averaged over this area whatever value we get is been captured by shadowing.

Whereas, if we average over the whole area we get the area mean which is np? So, there is when you the moment you do average there is kind of correlation that is given added. So, these path loss exponents or these sorry these standard these shadow fading values can be they would be correlated and one way of generating them through simulations would be following this particular model which is filtered Gaussian noise where you can say vk is the Gaussian random variable and this omega k is the value which is obtained at a particular location or at a particular iteration and there is a certain amount of memory that is involved which includes which is basically the correlation parameter and there is certain amount of randomness which is brought in by v k which introduces this Gaussian distribution.

So, kind of filtered Gaussian noise model is followed in order to include a correlated shadowing. Now for our particular course we do not need all these details of correlated shadowing and so on and so forth. What we can utmost use is the path loss exponent shadowing most important to remember is these models provide us with the average received signal strength as a function of separation distance along with certain random fluctuations we will be concerned with the signal attenuation only once, we are studying in mobile communications in a different subject then, you need even more details of shadowing to calculate the boundary coverage probability and so and so forth, with this we more or less summarize large scale propagation models what I would like to point out is to try out some of the some of the things or to try out few numerical.

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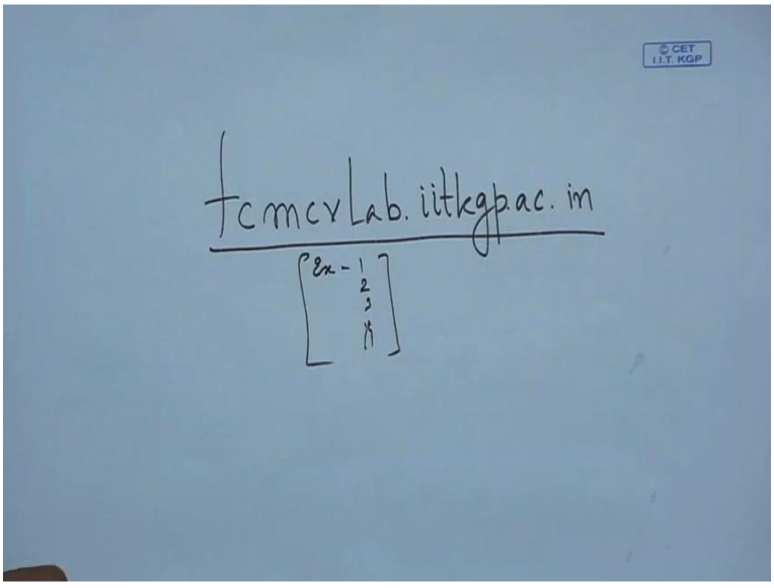


I would welcome you to visit the site fcmcvlab.iitkgp.ac.in. This is virtual laboratory which is sponsored by m h r d and it has been developed. So, 1 can use it for free there is no price required to be paid only required is internet access browser and it runs on java applets. So, you have to install java from the internet all the things are mentioned, if you have any difficulty you can always communicate with the teachers of this particular subject who can help you. So, in this particular website you will find a few examples or few exercises 1, 2, 3 and 4 on 4 and so on. So, you can try out these examples yourself which are tutorials are given in the particular website which you can read by yourself and you can try them out there could be some security issues that during installation or during trying out the experiment all detailed instructions are mentioned.

So, whatever we have discussed in this particular class and the previous lecture you could try out some of the examples, which would help you cover these particular lectures there are some advanced topics again the references are mentioned in the particular website as well as tutorials and numerical are worked out following them you can complete a few experiments as well which is not necessarily part of our discussion.

Thank you.