Advanced 3G and 4G Wireless Communication
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Lecture - 36
Ground Reflection and Okumura Models

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

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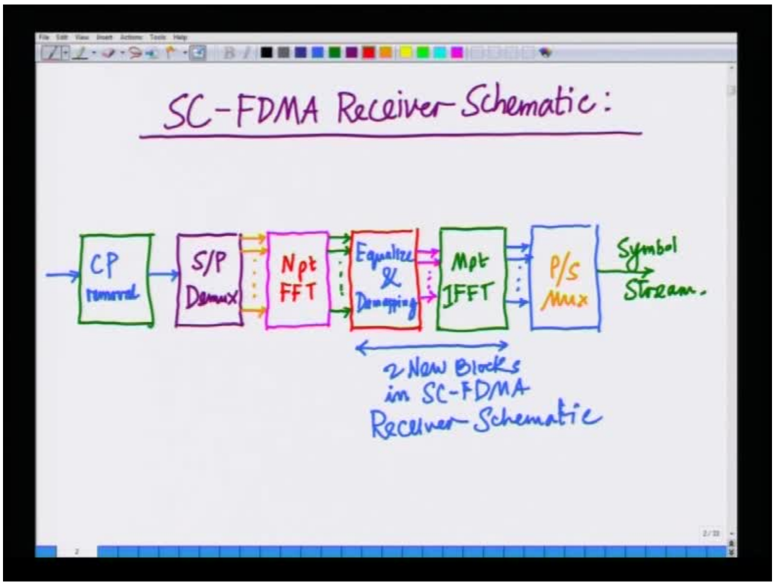

In the last lecture, we looked that is become concluded on discussion on SC-FDMA, that is single carrier frequency division multiple access, which is which is one of the solutions to reduce PA PR in an OFDM system, and we said in SC-FDMA.

We introduce two blocks; one is the equalization and de-mapping block, the other is the M point IFFT to essentially reverse the N point FFT, that is but done at the transmitter in this SC-FDMA system.

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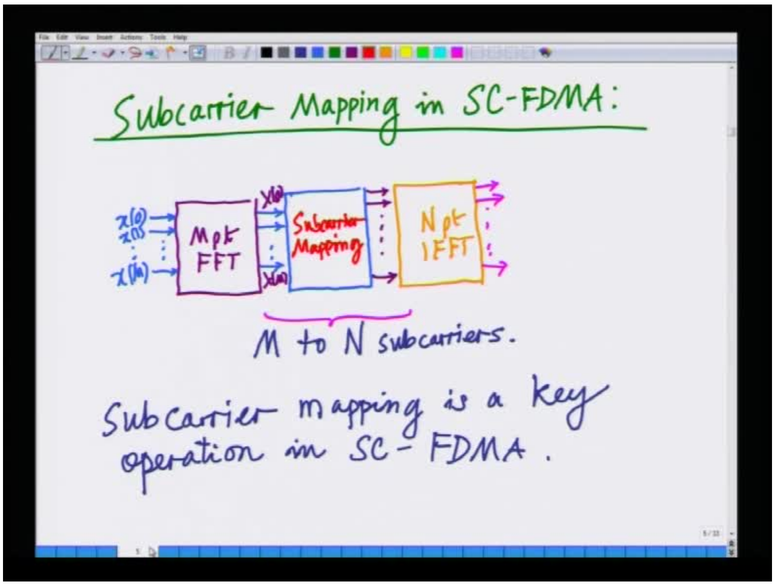

In addition we set that this sub carrier mapping from M to M, that is the output at the M point FFT to the input of N point IFFT is a critical aspect of in a SC-FDMA system, and then we said there are many ways to do it.

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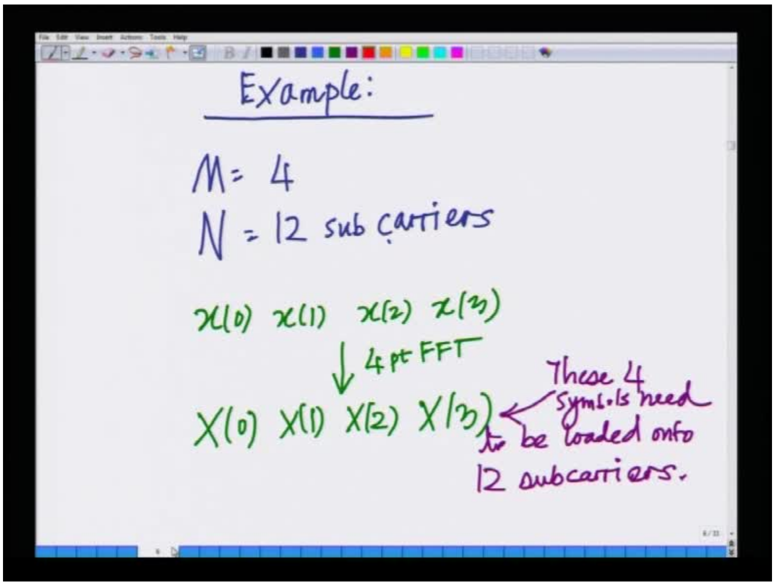

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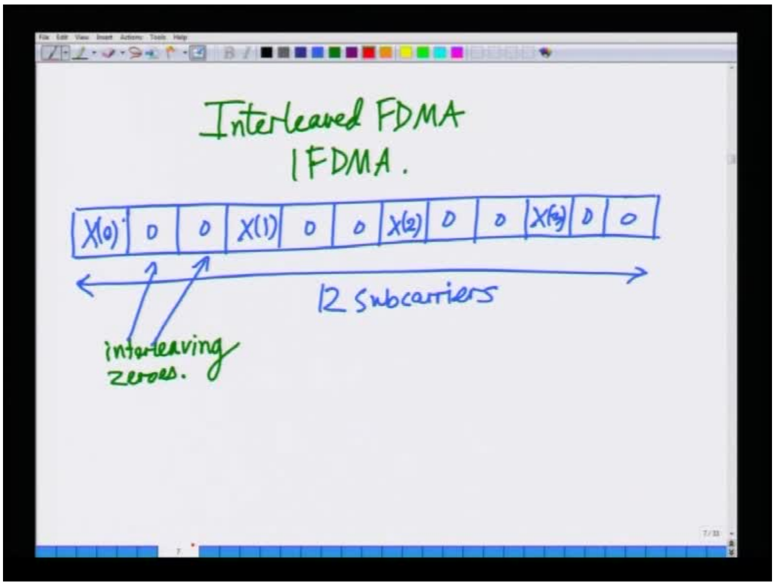

One is to interleave zeros in between that is use space your M outputs of the FFT regularly over N, and interleave the elements in between with 0 and this is known as interleaved FDMA or IFDMA.

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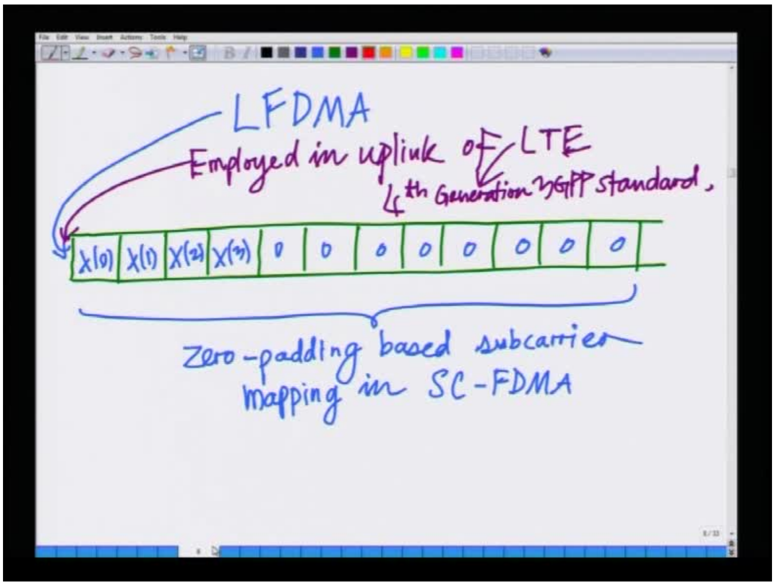

And we said the other is to simply use a zero padding, that is use that is stack everything in the beginning until the rest of the elements with zeros, this is known as LFDMA and this is this is employed in the uplink of l t which is of course, the fourth generation wireless mobile standard alright.

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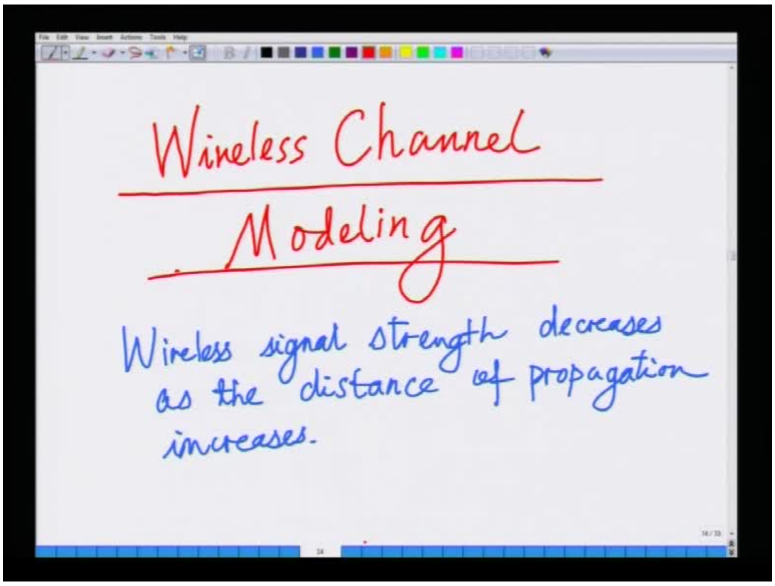

And, with this we concluded our discussion on OFDM we summarize the various aspects that we looked at in OFDM, and then we moved on to wireless channel modelling, in which we said the wireless channel decreases as the signal strength decreases in a typical wireless scenario as a function of the distance, and in order to characterize cellular scenarios that is the power that is received as at the cell edge, and so on or to characterize the transmit power we wanted to understand these channel models.

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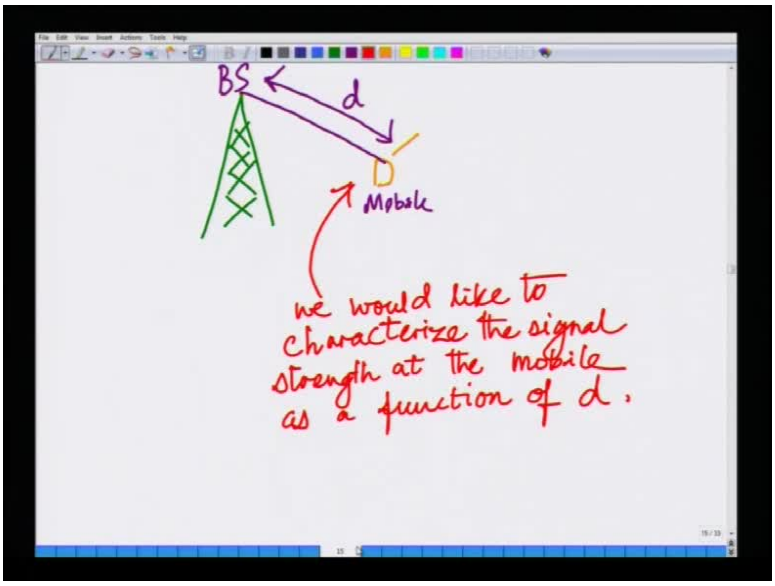

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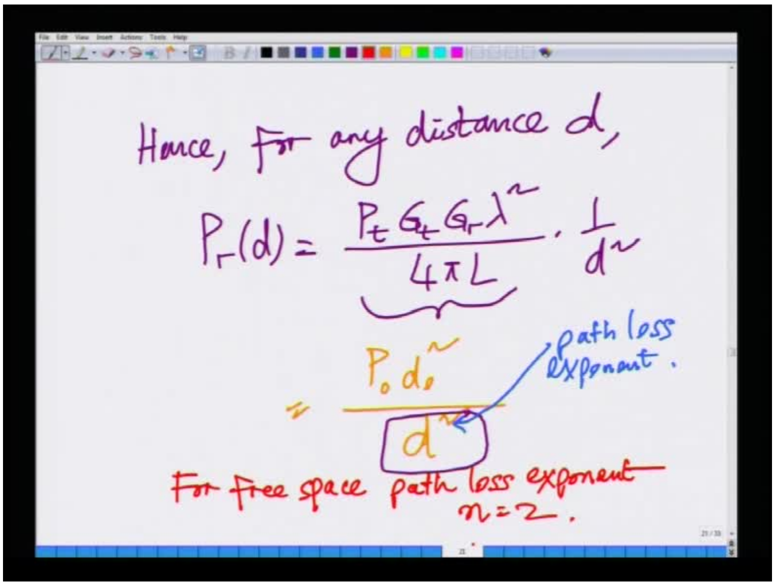

And we set typical in free space the channel power decreases with the square of the distance that is the path loss exponent is to that is power decreases as d square alright.

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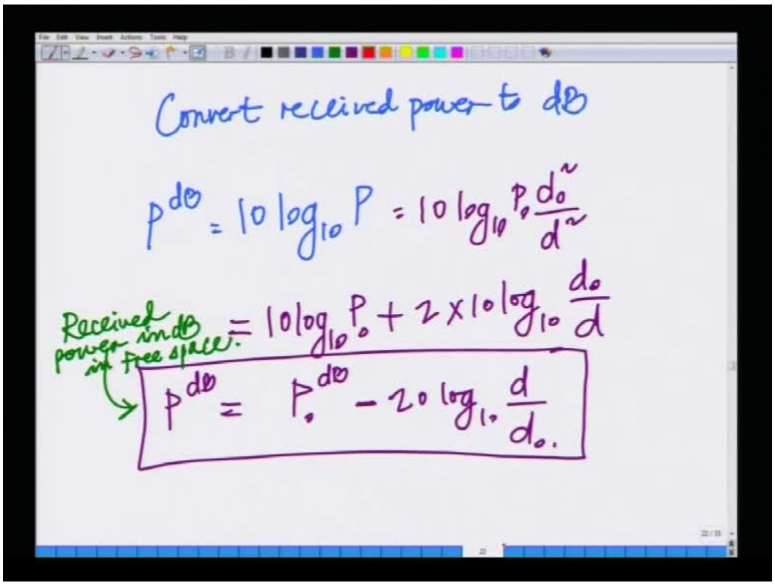

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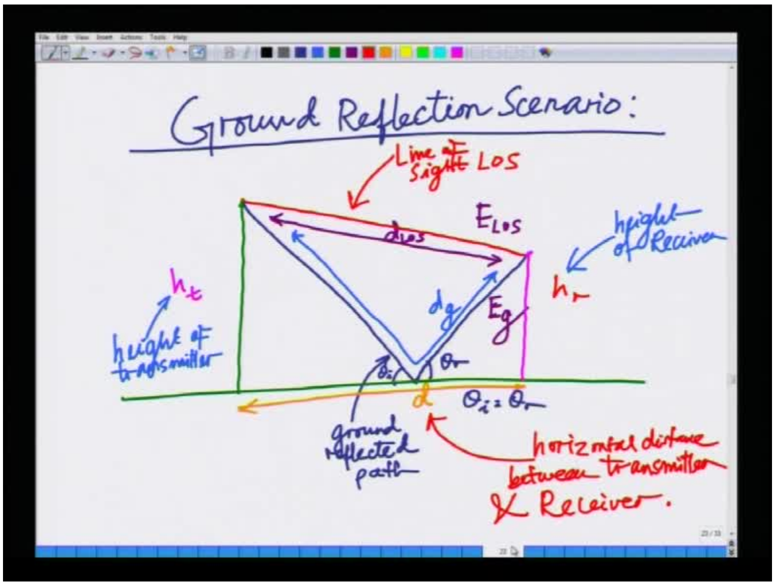

However, we wanted to look at other urban scenarios in which cellular scenarios typical invest there are obstructions, and we set the path loss exponent in such scenarios can be higher, we started looking at a ground reflection scenario in which between the base station and the mobile, there is a line of sight path and there is also a reflected a ground reflected path, there is line of set path as a distance d LoS, the ground reflected path as a distance d g, height of the transmitter as h t, height of the receiver is h r the distance between the transmit horizontal distance between transmitter and receiver is d, and we wanted to look at the received signal strength as a function of this distance d.

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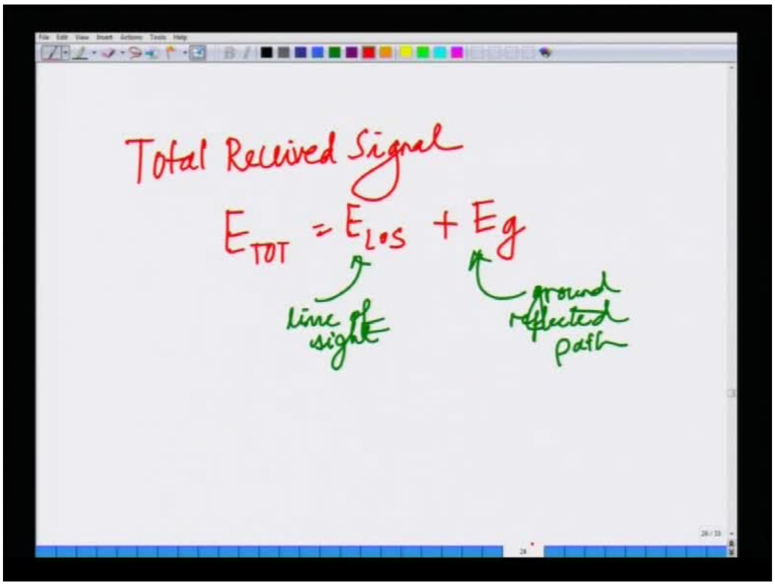

And we set the total received signal strength is total E total is E LoS plus E g that is the point at which we are, so, let us continue from this point in the lecture today...

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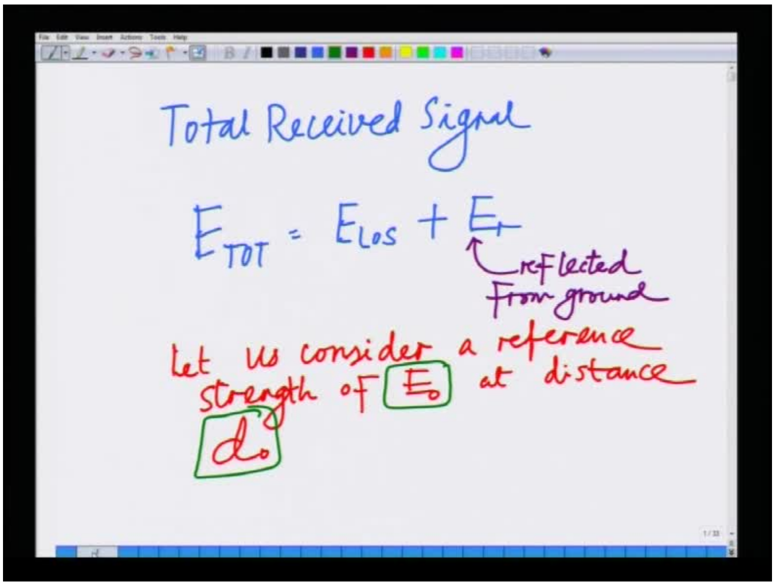

And we said that E total received signal total received field strength E total is simply the LoS plus the ground reflected, this is the ground reflected path, this is simply the sum of these two convey, this let me mention, this is reflected from the ground, and let us consider similar to what we have done earlier. Let us consider let us consider a reference strength of E naught at distance d naught, that is I am considering this as my reference, that is e naught is the signal strength at the distance d naught.

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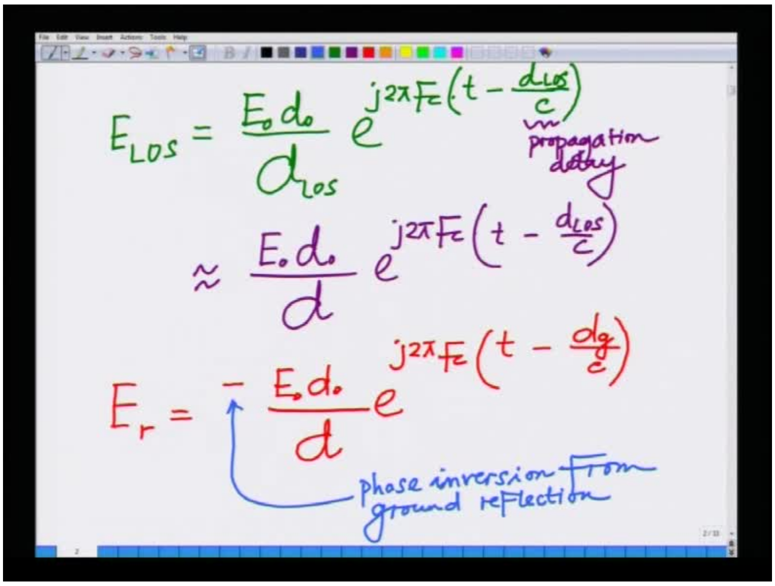

Then my E LoS thE LoS received signal strength E LoS is given as follows E LoS is nothing but, E naught d naught by d LoS, because remember the power decreases as d square the signal strength simply decreases as or the amplitude decreases as 1 over d, and the phase factor of course, which is the most important thing that is given as 2 phi F c, and a function of the delay a raising because a function of the propagation delay a raising because of the distance.

This is simply the propagation delay, which results the phase difference at the receiver that is the phase difference between receiver, and that is the phase log at the receiver compared to the transmitter, and this I will approximately what I will do is approx approximate d LoS by d for this component for the signal strength component, and I am going to simply write this as e naught d naught by d e to the power of j 2 phi F c t minus d LoS by c alright.

Now, similarly, of course,, we have another component which is the ground reflected component, and this ground reflected component I am going to write this ground reflected component as follows, similar to above the strength is E naught d naught again I am going to approximate d g by d into e power j 2 phi F c t minus d g, this is the propagation delay which is related to the distance d g; however, there is also now a factor of minus 1 and that a raises because of the ground that is a phase inversion at the ground reflection so. This essentially a raises because of the phase inversion from ground, this a raises because of the phase inversion from the ground reflection.

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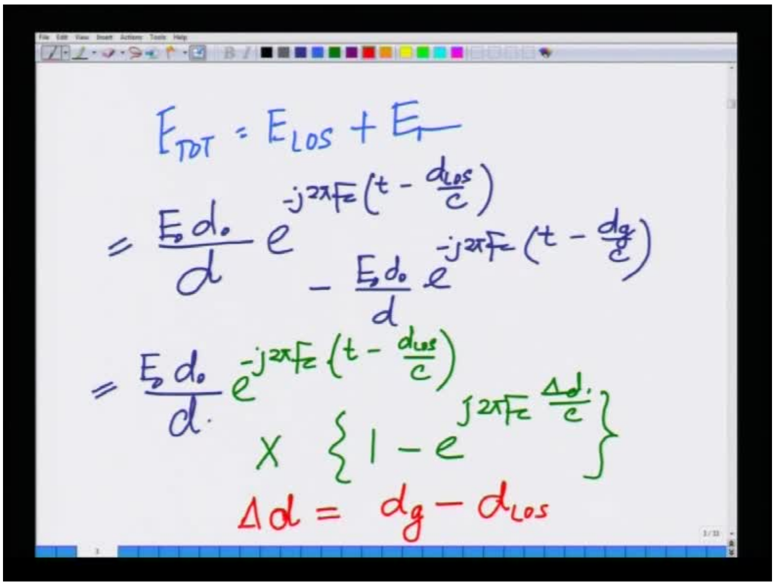

Now, the received signal is nothing but, the sum of these two signals that is E LoS and E r, and hence the total as we had set before is nothing but, E LoS plus E r, which is essentially E naught d naught by d e to the power of minus j 2 phi F c t minus d LoS by c minus E naught d naught by d e to the power of minus j 2 phi F c t minus d g by c, that is remember this first term is E t naught, second term is E r, and the minus a raises because of the phase inversion at the ground reflection and this is nothing but, E naught d naught by d into e power minus j 2 phi F c t minus d Los by c over c into times 1 minus E power j 2 phi F c delta d over c, alright will we are isolating this term E naught d naught by d in to this phase term times 1 minus e power j 2 phi F c delta d over c, where this delta d is an important factor, this delta d is essentially the difference, that is this difference the path length difference, that is difference between the distance of the distance of the length of propagation in the ground reflection minus the length of propagation for the line of sight path.

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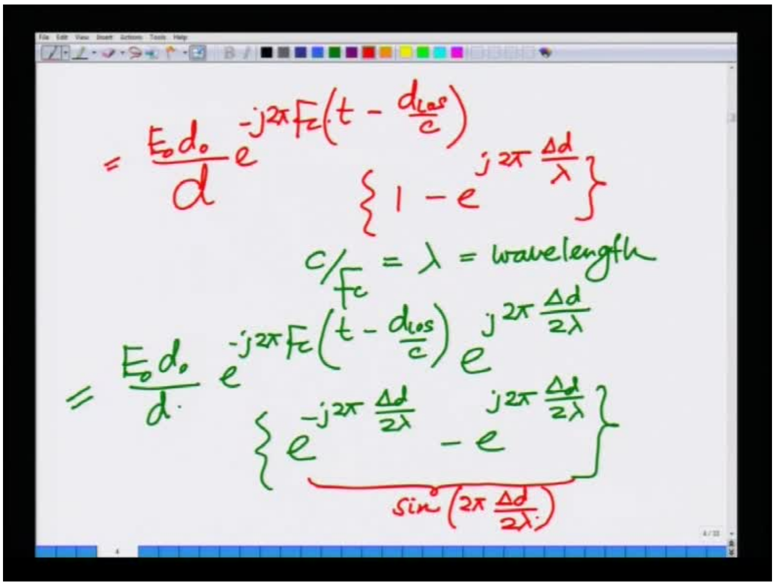

And this I am going to simply right as follows this is E naught d naught by d e power minus j 2 phi F c t minus d LoS by c into 1 minus e power j 2 phi and delta d over c over f c is nothing but, lambda, hence I can write this as delta d over delta d over lambda.

So I am going to write it this way essentially this is this is essentially what we set this is E total is E line of sight plus the E reflected, and there is a minus sign because of the phase inversion at the ground reflection, here for this simplification we have used the fact that c over F c, that is velocity over carrier frequency is nothing but, lambda which is essentially the wavelength of the length.

And this I can further simplify as follows this is E naught d naught by d e power minus j 2 phi F c t minus d LoS by c into e power j 2 phi delta d divided by 2 lambda times e power minus j 2 phi delta d divided by 2 lambda minus e power j 2 phi delta d divided by 2 lambda and this factor of course, this is nothing but sin of 2 phi delta d divided by 2 lambda.

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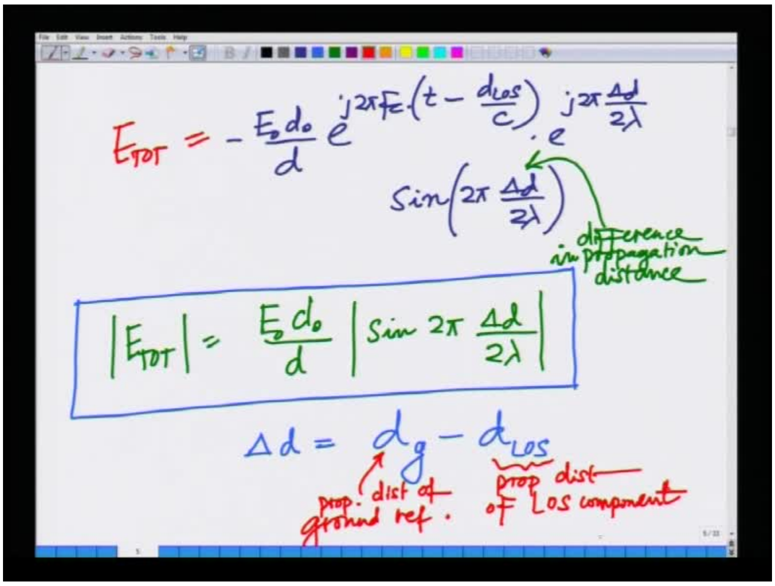

Hence, net I can write E total equals I am sorry this is of course, minus sign hence I can write this as E total equals minus E naught d naught by d e to the power of minus j 2 phi F c t minus d LoS by c into e power j 2 phi delta d divided by 2 lambda into sign 2 phi delta d divided by 2 lambda, look at this difference between the distance that is difference between the distance d g minus d LoS, that plays a critical role this is nothing but, the difference in the propagation this is nothing but, the difference in the propagation distance, and naturally because of the phase lag that is there in these two ways depends on the distance.

Hence the phases with which they are depends on the that difference of the distance which essentially determines what is the resultant amplitude.

And finally, if I look at the magnitude of E total both this exponential factors they vanish, because they are phase factors hence the magnitude is nothing but, E naught d naught by d magnitude sin 2 phi delta d over 2 lambda alright, and this is essentially the expression that we have for the net magnitude, where delta d let me remind you again is nothing but, d g minus d LoS, this d g is the path length or the distance of propagation of the ground reflected component propagation distance of ground reflection, and this d LoS is the propagation distance of LoS of the line of sight component.

So, now what we have do is we want to simplify this expression further, which means I want to simplifies these simplify this delta d, which is the difference between distances d g and d LoS. So, first I will start by computing both d a d g and d LoS.

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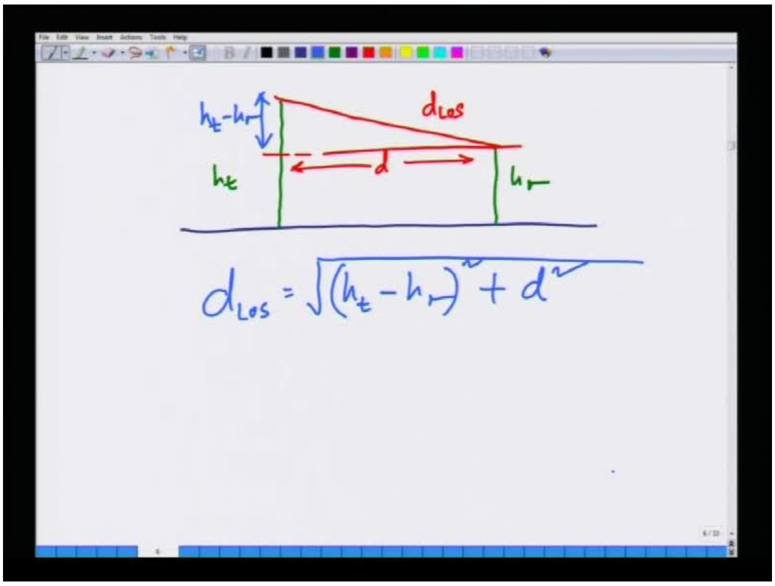

So, let me start first by computing the easier one that is E LoS and for that let me go back to the diagram we have height of transmitter is h t we have height of receiver is h r, hence if I draw this line of sight component d LoS. Let us look at this triangle this distance is the horizontal distance which is d and also I have the height of this triangle, which is now h t minus h r this is right angle triangle with sides h t minus h r and d, hence d LoS is nothing but square root of h t minus h r square plus d square, hence d LoS is h t minus h r square plus d square.

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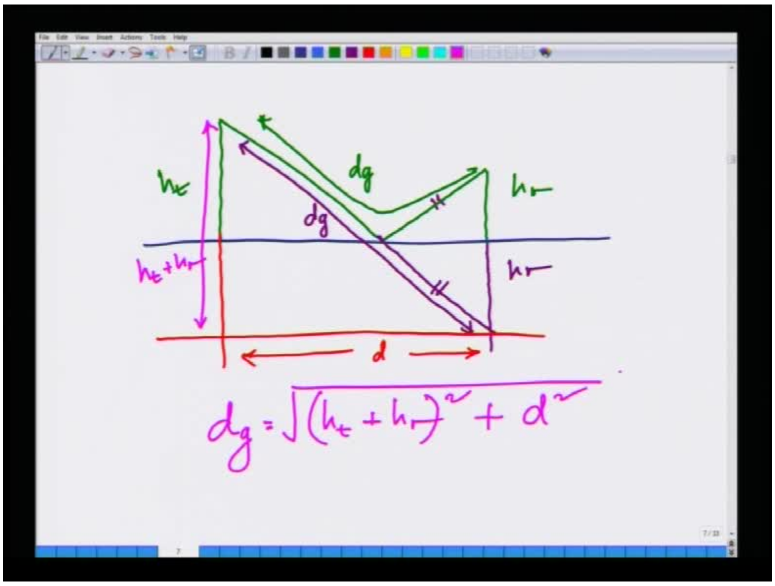

Similarly, now let us compute d g that is slightly involved but, never the less again intuitive I have this over here I have again h t h r I have the ground reflected components such that theta incident is basically theta reflected, the length of the ground reflected component d g is nothing but, the sum of these two components.

What I will do is I will here I will use the method of images I am going to extend this below by h r, and I have also going to extend this below you can see that these two are equal in length, hence this now is nothing but, d g and hence if I look at this triangle essentially with distance length d and this length now becomes obvious that is h t plus h r hence this is d g is nothing but, the side of a right angle triangle with sides h t plus h r and d, hence d g is square h t plus h r whole square plus d square.

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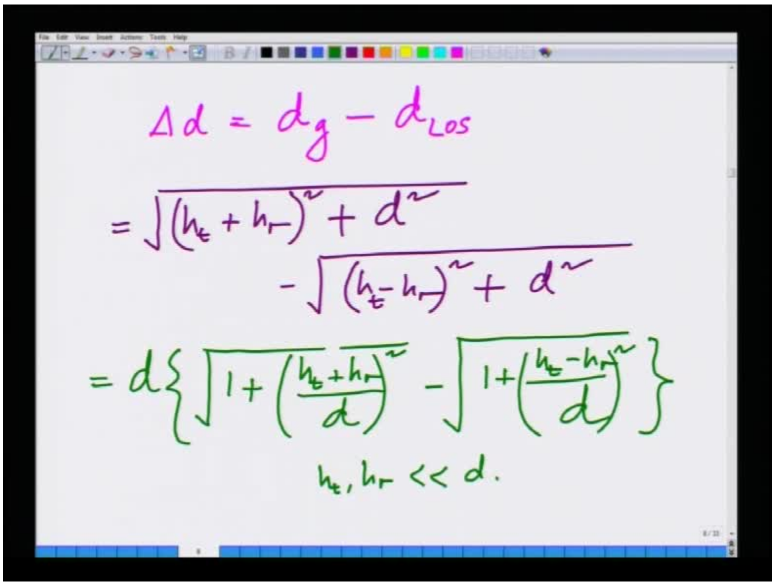

Hence, what I have net is essentially delta d equals d g minus d LoS, which is basically h t plus h r whole square plus d square minus h t minus h r whole square plus d square, which if I take d common outside this is square root 1 plus h t plus h r by d whole square minus square root 1 plus h t minus h r by d whole square, alright. And here I am going to use an approximation that h t comma h r are much much smaller than d, so h t plus h r h t minus h r so on and so forth, all are much smaller compare to d.

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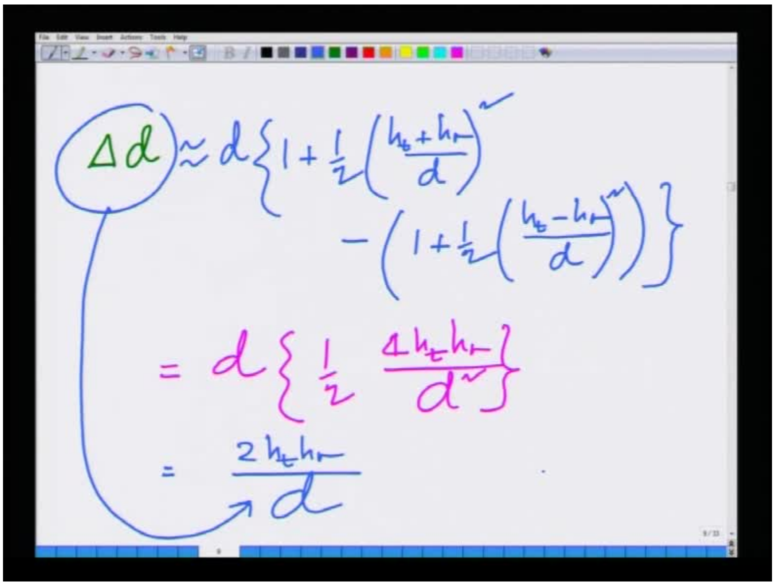

Hence, delta d is approximately d into 1 plus half h t plus h r by d whole square minus 1 plus 1 by 2 h t minus h r by d whole square, which is essentially equal to d times, if I simplify this the once cancel this is a 1 by 2 h t plus h r whole square minus h t minus h r whole square which is essentially 4 h t h r by d square which essentially is equal to 2 h t h r by d, hence what do I saying is this delta d distance, this is approximately equal to 2 h t h r by d.

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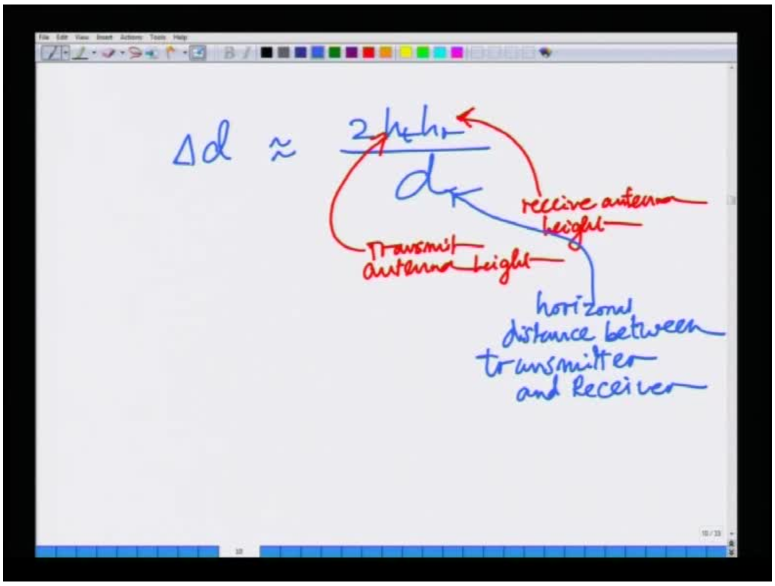

Hence, delta d approximately equal to 2 h t h r by d, let me again remind you what this quantities are h r is receive antenna height h t is the transmit antenna height and d is the horizontal distance between transmitter and the receiver, so this what we have we set delta d which is the difference between the paths d g minus d LoS, this is equal to 2 h t h r by d, where h t is the transmit antenna height, and h r is the receive antenna height, and d is the horizontal distance between the transmitter and the receiver.

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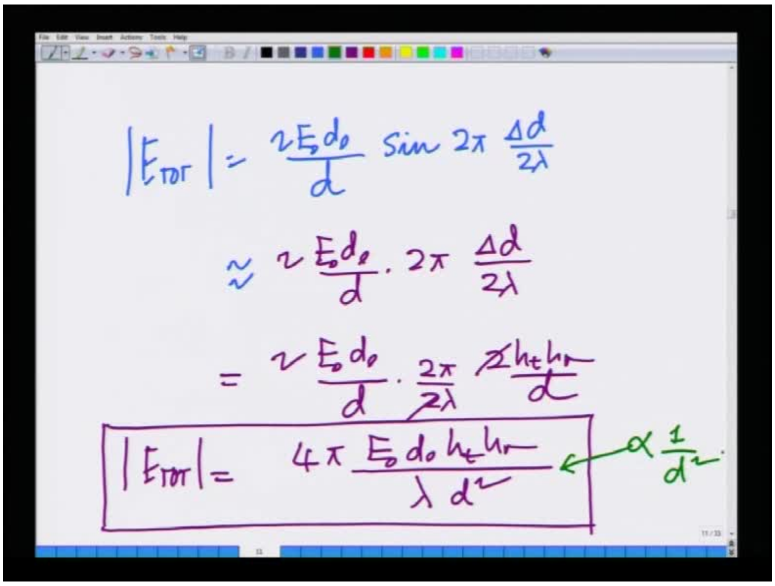

Now, I am going to substitute this delta d back in the expression, where we are saying magnitude E total is nothing but, twice E naught d naught by d into sin 2 phi delta d by 2 lambda. I am going to say, this is delta d is fairly delta d is fairly small. I am going to say this is approximately equal to 2 E naught d naught by d 2 phi delta d divided by 2 lambda, since for small theta sin theta is approximately equal to sin theta, and now I have this essentially I am going to replace by 2 lambda into 2 h t h r by d, which is essentially equal to 4 pi E naught d naught h t h r by lambda d square.

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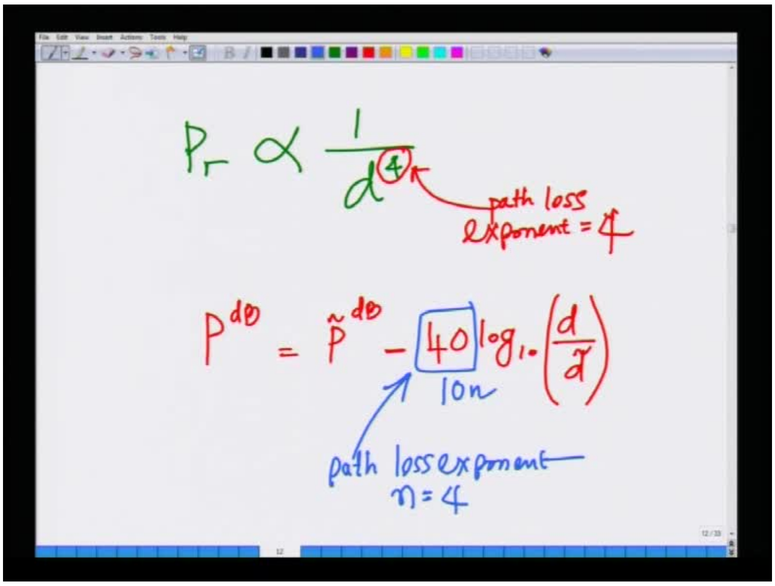

Hence, magnitude or received signal strength the most important idea, here is that the magnitude of the received signal strength is proportional to 1 by t square, which implies the power that is received. So, is the magnitude of the strength signal strength is power proportional to 1 over d square the power naturally is proportional to 1 over d to the power of 4, since the power is proportional to the square of the signal strength, which means the path loss exponent the powers now is decays as the fourth power of distance, hence this means path loss exponent equals to 4, hence when we have obstructions now essentially when we have reflections, and so on the path loss exponent essentially increases alright, and they will just believe what we expect in urban and cellular scenarios.

Hence again going back to our free space loss equation one can write the received power in d B is p tilde some reference power at distance d naught minus 40 log 10 d over d naught, which is there is a 40 d B per decade kind of decrease in power b p tilda is some reference power at distance d naught, this essentially is the main aspect is the major aspect, which says which a raises because path loss exponent n equal to 4 and this is essentially 10 times n.

So that is what we are saying essentially what we are saying is that n urban scenarios, or in cellular scenarios because of the reflection and scattering what we might have we do not have finish the propagation, which means a essence what we are going to have lot of interference, and we are going to have reflections scatter components adding up, hence the effective path loss exponent, f you look at it at the receiver it looks larger than two it is in the range of 2 to 4.

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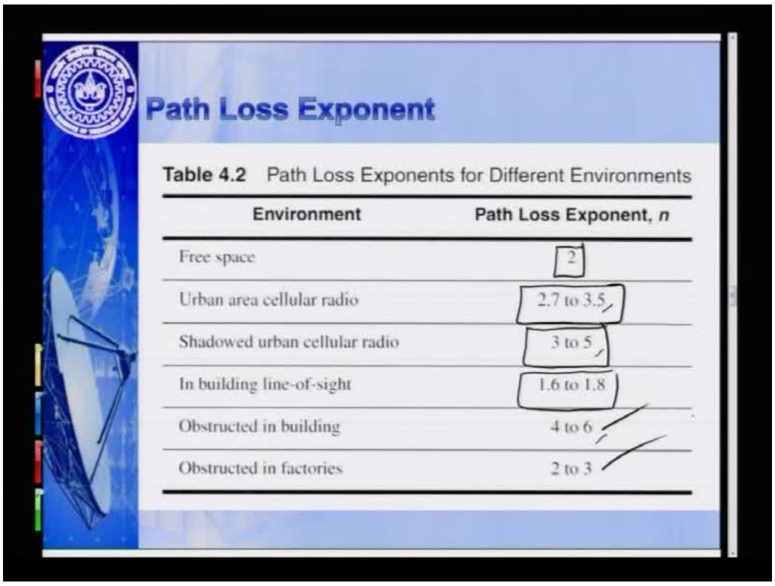

And let us look at some tabulated scenarios in practice, let us go to this table if you go to this table we can see path loss exponent for various scenarios for free space it is 2 for urban cellular radio it can be anywhere from 2.7 to 3, so it is around 3 in shadowing, in fact, it is increases from 3 to 5, so it can reach as hour as five in building in line of sight as we can see it is lower than you see, and especially if you have obstructions it raises even beyond 4 and 6, but normally in outdoor cellular scenarios this path loss exponent essentially this is of the order this is of the order of 2 to 2 to 3, alright n equals 2 to 3 I mean this as the order of 2 to 4 an average around 33.5 and so, alright it depends on the exact scenario that you are considering so that is essentially our discussion on path loss scenario.

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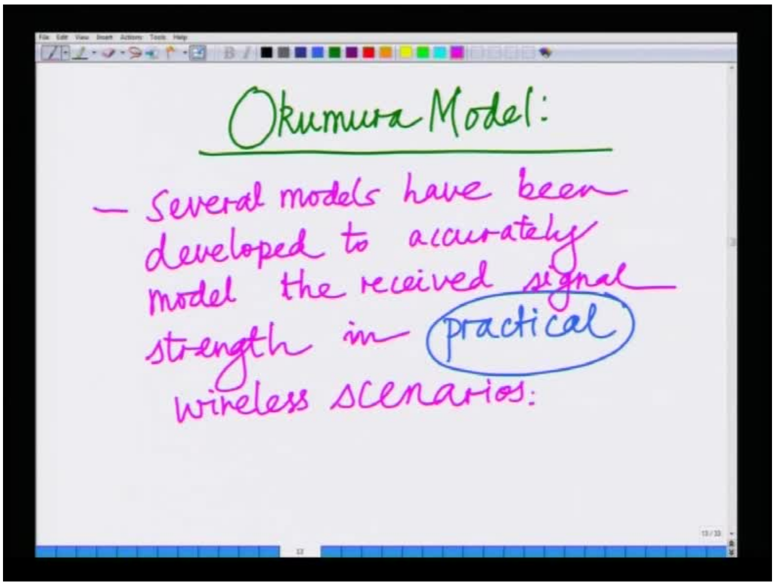

Now, the sizzler to calculate or give as an approximate idea of what is the received signal strength in several urban scenarios, there have been several models standard channel models, that have been propose taking in to a lot of these urban sub urban sort of factors into consideration, that is to give as an idea of or accurately or more or less accurately predict the signal strength that is certain the strength, these are for instance okumura model that is one such model.

The next we are going to look at this model.

So, to characterize the distance signal strength in urban scenarios we have several models the okumura model is one such model simply put it states that, so first let me again read point several models have been developed to accurately to accurately model the received signal strength received signal strength in practical wireless scenarios, the key word here is practical in practical alright.

So, this several models that have been developed essentially you to characterize this wireless strength in practical scenarios or specially cellular scenarios, and so on.

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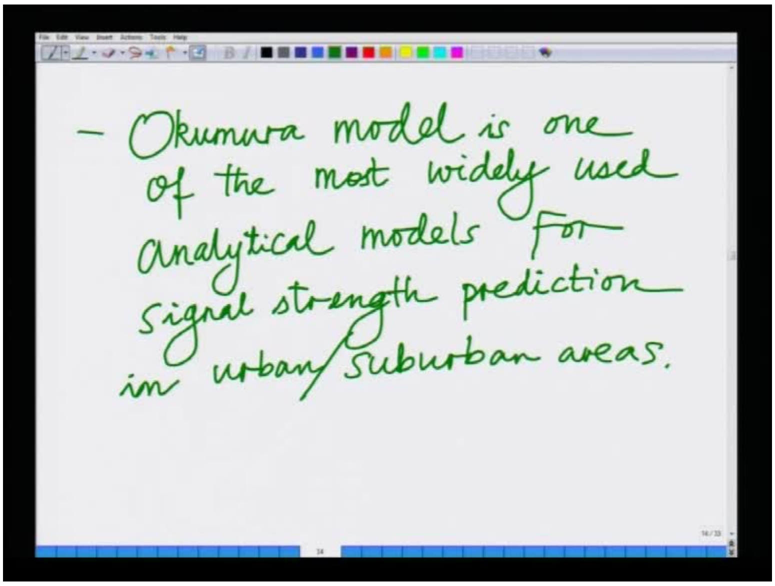

And this okumura model is one of the most widely use such models essentially it for signal strength prediction in urban sub urban areas. So, this okumura model is one of the more popular models.

So, it could be summarize that point here, okumura model is one of the is one of the most widely used is one of the most widely used analytical models models for signal strength prediction for signal strength prediction in urban slash in urban sub urban areas, this is one of the more widely used models.

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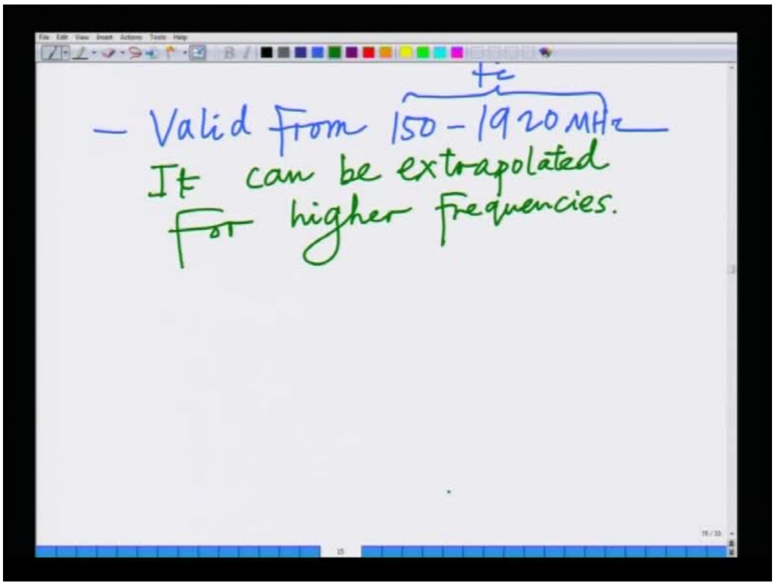

And even though this the okumura model is valid from 150 to 1920 mega hertz this can be extra polated for higher frequencies. So, it is valid from 150 to 1920 mega hertz this is the range of the carrier frequency; however, with extra polation it can be used for how a higher frequencies.

It can be extra polated; however, it can be extra polated for higher frequencies. So, what you are saying essentially is this okumura model is one of the more popular models employee to characterize signal strength in urban practical scenarios which is urban, sub urban cellular scenarios, and which is one of the most widely used analytical models, and it can be exploid used write round the 200 mega hertz range to essentially we can going to use it for the 2.5 giga hertz range also essentially about about the covering most of the cellular band essentially.

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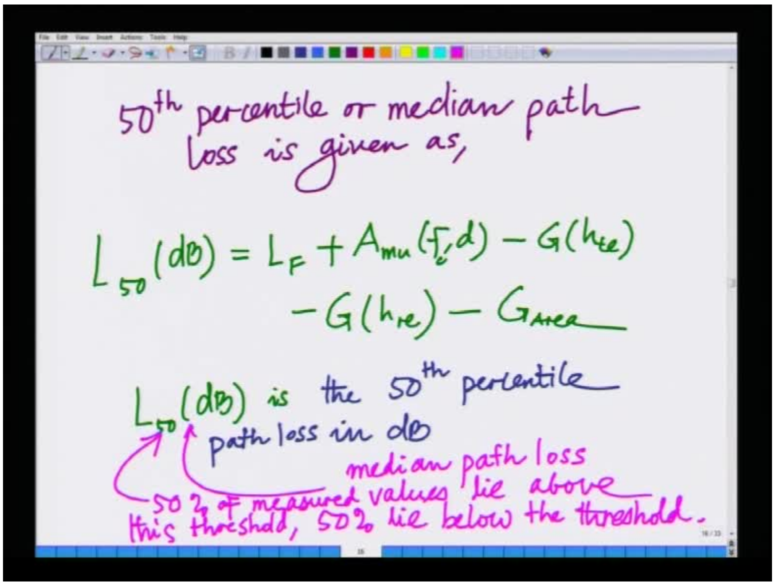

So, what is the okumura model, if you when look at the model okumura model it predicts the 50^{th} percentile loss the 50^{th} percentile loss or the median loss or median path loss is given as what is the 50^{th} percentile loss 50th percentile is essentially saying that half of the measured values lie above this half of the measured values lie below this. So, that is the essentially the same as the median path loss alright.

The 50th percentile or the essentially the median path loss is given as L 50 in d B this is the 50th percentile path loss is L F, which is the free space path loss plus we are going to see what each of this factors is shortly A mu, which depends on the frequency that is the carrier frequency and the distance minus the gain a gain factor a raising out of the transmit antenna minus a gain factor a raising out of receive antenna in us a gain factor that is a raising out of the area, this is all path loss, so all the gains have to been essentially subtracted from the loss L 50 d B.

Let us explain what each of these components is L 50 d B as we already said is the 50th percentile path loss in d B, which essentially says it is the median path loss this essentially means this is the median path loss and 50 percent of the measured values lie above this threshold, and 50 percent of measured values lie below the threshold. So, 50 percent of measured values lie above this threshold and 50 percent lie below threshold 50 percent lie below this threshold.

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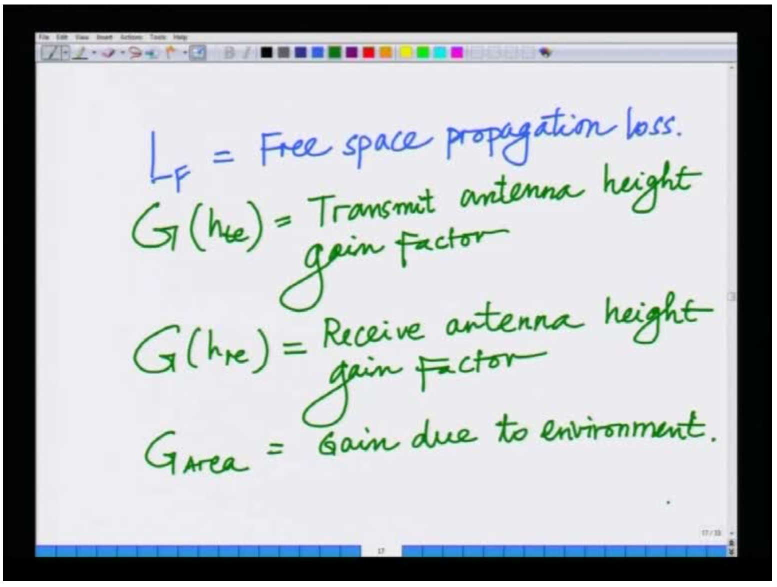

L F the factor the other factor is essentially the free space propagation loss, this is the free space propagation loss, we are going to characterize this slightly this L F is the free space propagation loss, G h t e is that you got the transmit antenna height gain factor, this is not be confuse with the gain of the transmit antenna but, this is the gain a raising out of the height, hence this is the transmit antenna height gain factor, it is a raise it is dependent on the height of the transmit antenna.

Similarly, G h r e is the transmit is the receive antenna height gain factor that this gain is a raising because of the gain that the height of that receive antenna, and normally you can see if the transmit antenna and receive antenna are mounted high then there is less obstruction, which means less interference which means more energy that is received at the receiver.

So, as a function as a height increases these gain increases, which means these subtract from the path loss therefore, the effective net path loss decreases essentially that is what this means and G area, G area is the gain due to environment equals this is the gain due to the environment for instance.

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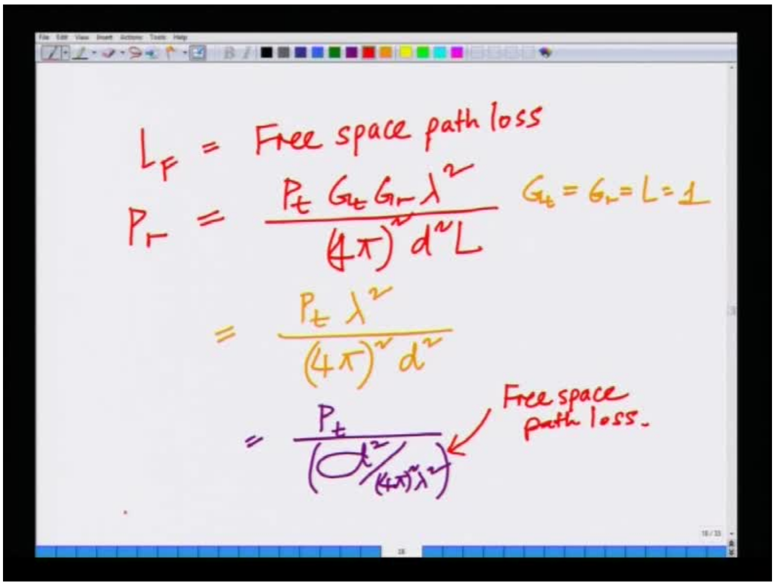

let go to the free space path loss L F equals the free space path loss, we already said in free space the received signal power as a function of distance is nothing but, P t equals G t G r lambda square divided by 4 phi square d square L, where p t is the transmit power G t is the transmit antenna gain G r is the receive antenna gain remember, these are the radio frequency gains lambda square is the wavelength 4 phi square, and d square is the distance, L is the system loss factor. Let us assume an normal scenario and let us set G t equals G r equals L equals 1 that is I am considering, now normal antennas the gain factors are 1, and there is no system loss factor in which case this become equal to P t.

Lambda square by 4 phi square d square, which essentially can be written as P t divided by d square divided by 4 phi whole square Lambda square, and this is now nothing but, this factor d square divided by 4 phi square Lambda square nothing but, this is nothing but, the free space path loss, this is nothing but, the free space path loss.

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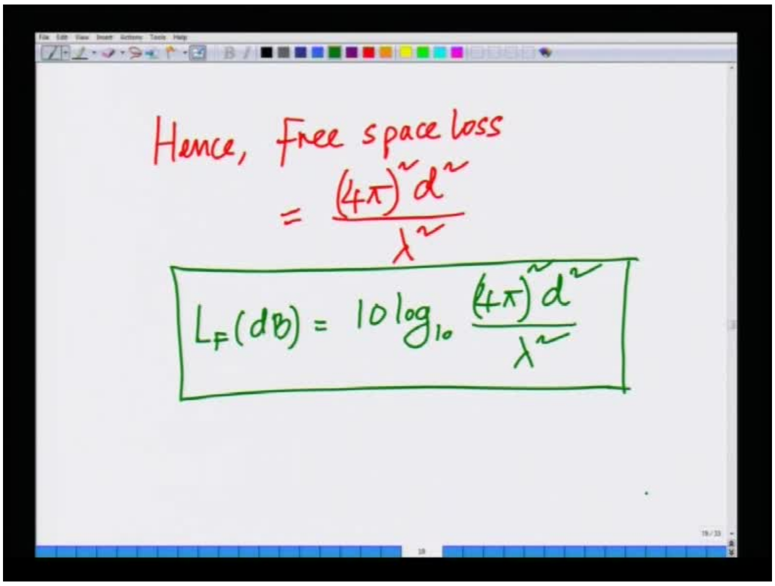

Hence, the free space loss is equal to 4 phi square d square divided by Lambda square, hence the free space loss in d B is nothing but, 10 log 10 of four phi whole square d square by Lambda square this is essentially the free space loss in d B s, so this is the expression for the L F component.

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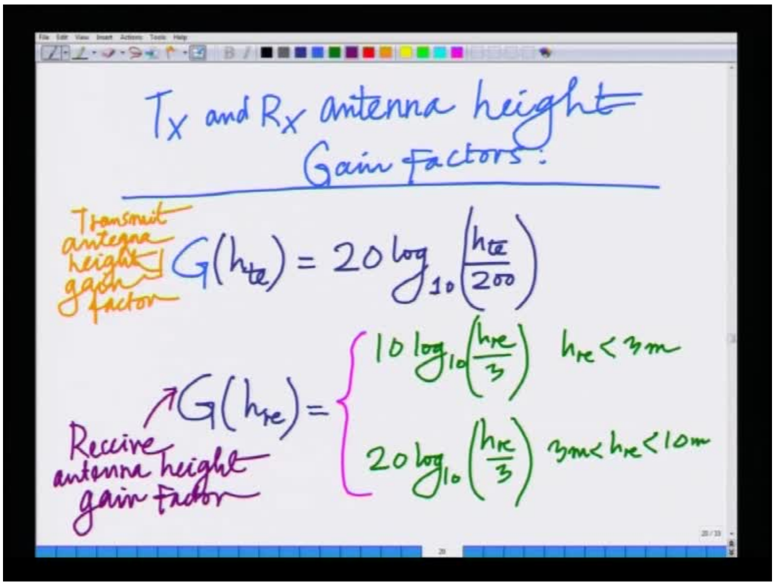

Now, let us look at the T x and R x antenna height gain factors, now let us look at the transmit and receive antenna height gain factors and again I would like to stress that these are not the gains of the transmit and receive antennas but, these are the reductions in the path loss of the gains that are a raising, because of the mounting height that these are the height gain factors, which result in less obstruction as the height increases, hence reduction in the path loss alright.

So, please make those distinctions. So, G h t e is the transmit antenna height gain factor is given as 20 log 10 h t e by 200, that is this is the transmit antenna height gain factor and the receive antenna height gain factor G h r e that is given as follows that is given as 10 log 10 h r e by 3, if h r e is less than 3 meters, and that is given as 20 log 10 h r e divided by 3 is 3 meters less than h r e less than 10 meters alright. So, we are saying there are two gain factors; the first one this is the transmit antenna height gain factor, and the second is essentially the r x antenna.

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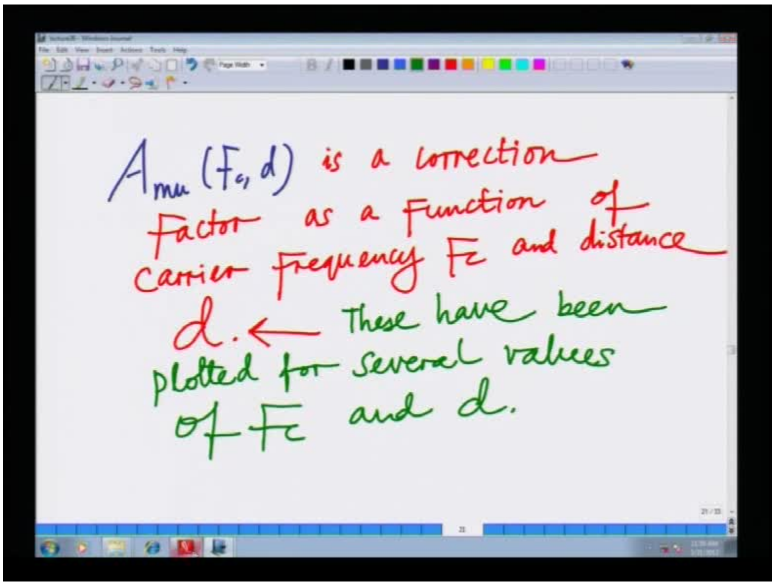

The receive antenna height gain factor, and G h t e as the function of the transmit antenna height is given as 20 log 10 h t e or 200, and G h r e is the function of the receive antenna height is given as either 10 log 10 h r e by 3, if h r e is less than 3 meters or 20 log 10 h r e divided by 3, if h r e is in the range of 3 meters and 10 meters, and the other components which are A mu which are F c comma d, which depend on the carrier frequency, which is essentially a correction factor is essentially a correction factor is essentially a correction factor as a function of carrier frequency F c and distance d as a function of the carrier frequency F c and distance d, and these have been tabulated actually these have been tabulated for several values several frequencies and distances these are rather have been plotted these have been plotted for several values of carrier frequency F c several values of F c and d for instance.

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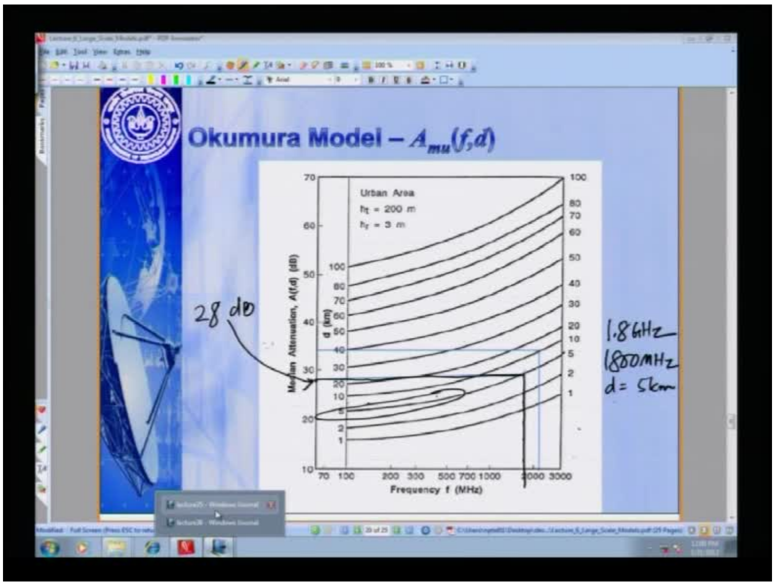

Let me go to that plot and show you how that plot looks like for instance, if you look at this, I have the okumura model and the A mu factor as the function of frequency and distance. For instance you can see on the these axis there is one curve for each distance 1 2, 1 kilometre 2 kilometre 5 kilometre up to 100 kilometres for instance, if I want to look at what is the A mu factor at 1.8 giga hertz, that is I want to look at 1.8 giga hertz at 1800 mega hertz essentially corresponding to a distance d equals 5 kilometre.

I have at 1.8 giga hertz I look at essentially basically, what it is and this is the curve remember, this curve here this is the curve for the distance of 5 kilometres and you can see that factor is something around 28 d B, so, that in A mu f d at 1.8 giga hertz and 5 kilometres is roughly about 28 d B.

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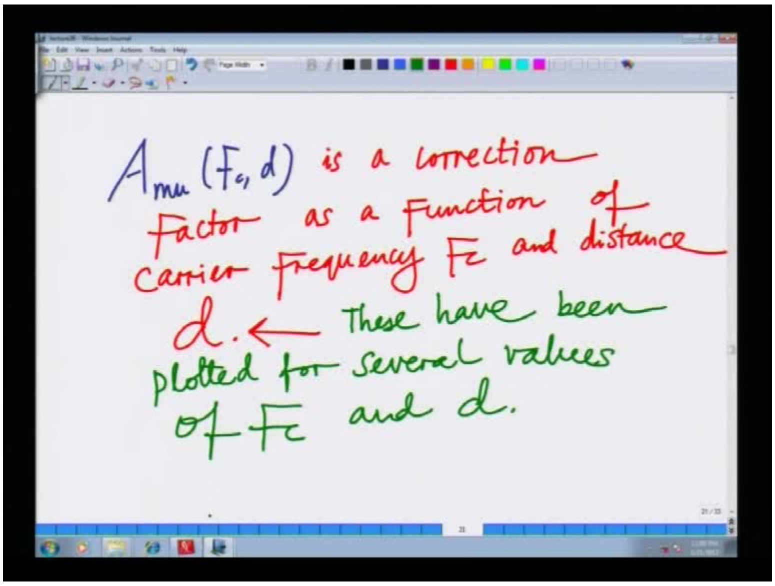

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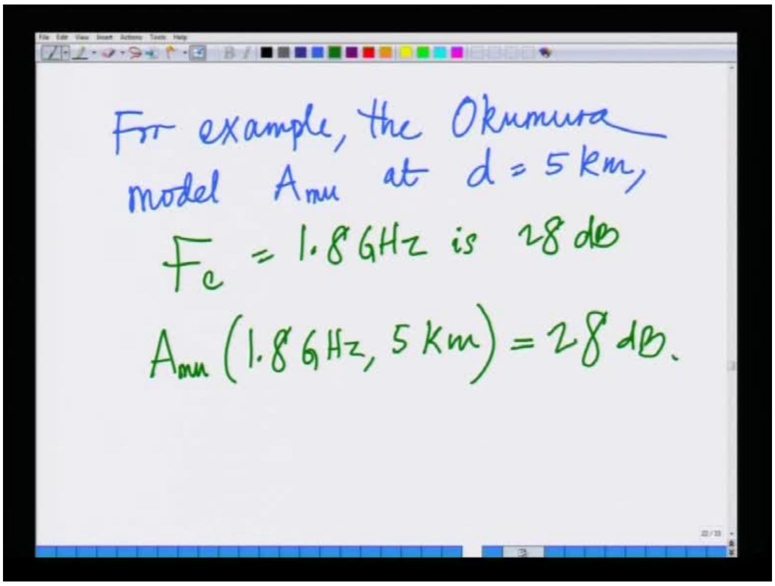

Hence, if I go back here for example, the okumura model A mu at d equals 5 kilometres, and F c equals 1.8 giga hertz is 28 28 d B that is if you write A mu of 1.8 giga hertz at distance 5 kilometres that is nothing but, 28 d B alright, so if you look at that factor, that factor essentially this a mu factor this example is 28 d B.

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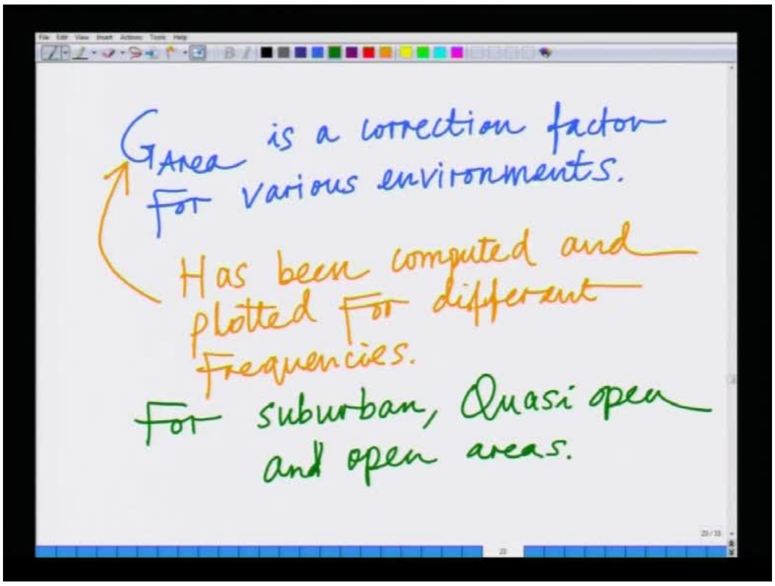

And similarly, lets come to the other factor the other factor is this G area factor, which is an area or environment dependent factor the other factor in the expression is G area, which is essentially it is a correction factor, it is a correction factor for various environments it is a correction factor for various environments, and it has been computed for different frequencies has been computed and plotted essentially for different frequencies, this has been computed and plotted for different frequencies for a particular set of areas for areas of the type sub urban, quasi I open and open.

So, this has been computed and plotted for sub urban, quasi open and open areas. So, this is G area is again a area correction factor, which essentially exists in the model, because let say you go from n, because okumura model is actually meant for an urban scenario.

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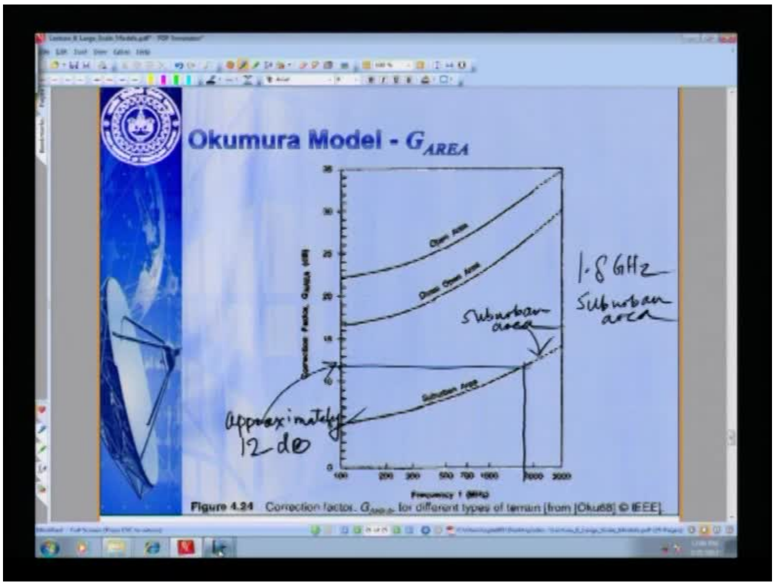

But, you move from an urban to sub urban scenario; obviously, the clut are decreases, hence the loss also decreases, then if you move to an open area then you would expect only the free space loss, because there is no obstructions as such hence there is a correction factor essentially as you move from urban area to sub urban areas to open areas.

For instance if you look at that plot that looks as follows for instance if you look at this G area plot for instance again I go back to the same question, that is 1.8 giga hertz and of course,, this is not does not depend on the distance, if you want to look at 1.8 giga hertz for a sub urban area I go to this point which is 1.8 giga hertz it is essentially around, this and this again is the plot for the sub urban area, and you can see this is approximately this is approximately 12 d B.

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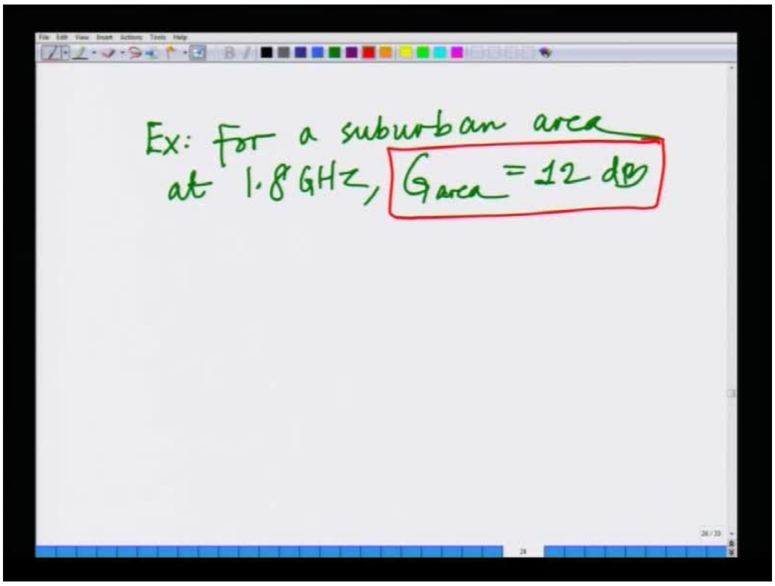

So, in essence I go back to this thing what we can say is for example, for a sub urban area at 1.8 giga hertz the G area factor is 12 d B, that is there is a gain of twelve d B which means twelve d B subtracts from the path loss essentially for this sub urban factor at 1.8 giga hertz alright. So, that is what this means, so that G area factor is essentially 12 d B for this sub urban area, so that comprehensively characterizes the a okumura model.

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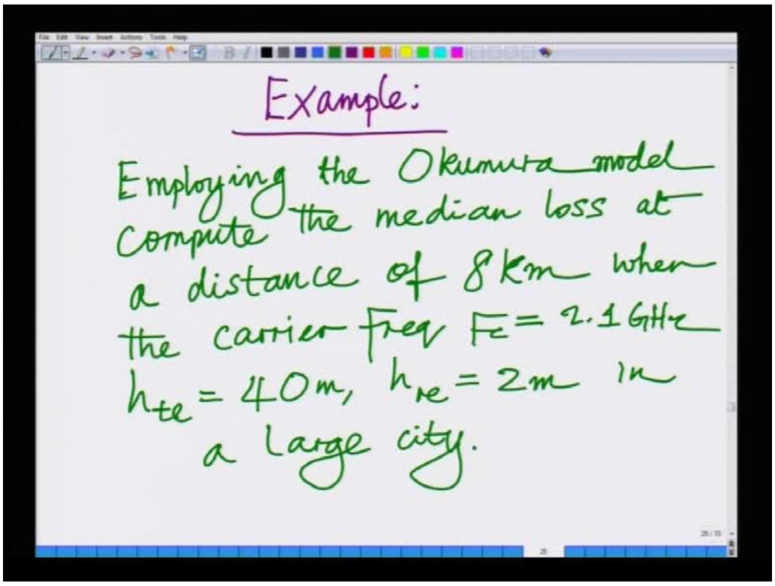

So, let us look at a simple example essentially to solidify or understanding essentially to illustrate the practical utility of this okumura model.

So, I want to look at an example here of how to use the okumura model in practice, so what the example we are going to consider is as follows employing the employing the okumura model compute the median loss, which is nothing but, the l fifty compute the median loss at a distance of 8 kilometres, when the carrier frequency F c equals 2.1 giga hertz, h t e the transmitter height equals 40 meters, h r e equals 2 meters in a large city alright.

So, what we want to do is we want to employee the okumura model find out in an urban propagation environment that is in a city at a distance of 8 kilometres, which are typically the radius of self cellular environments or cellular base stations that is 5 to 10 kilometres, and a carrier frequency of a 2.1 hertz transmitter mounted at height 40 meters, and a receiver height 2 meters roughly slightly larger than the height of a normal person, which is around the 1.5 to 2 meter range, that is a extreme range of a height of a person at 2 meters.

What is the average what is the average what is the average path loss look like which will give as an idea what is the transmit power that has to be transmitted by the base station. So, there is two accounts for this path loss essentially.

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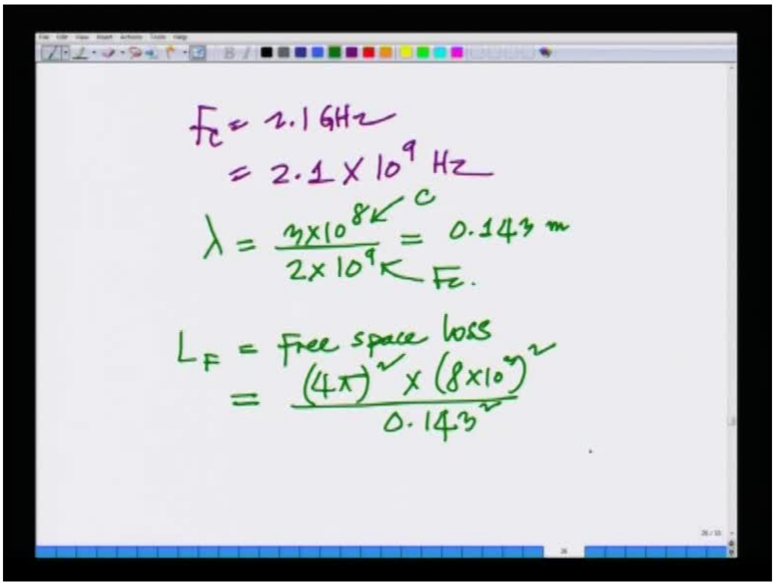

So, let us start by computing that we are given F c equals 2.1 giga hertz, which is again 2.1 into 10 to the power of 9 hertz, and we also know that this Lambda value Lambda equals 3 into 10 power 8 divided by 2 into 10 power 9 equals point 0.143 meters, this is nothing but, the velocity of light this is c, this is f c and c by F c equals Lambda which is 0.143 meter.

Hence the free space path loss we know is 4 phi d square divided by Lambda square, hence free space path loss L F equals free space or free space loss equals 4 phi square d square divided by Lambda square, which is 4 phi square into 8 kilometres, that is 8 into 10 power 3 whole square divided by Lambda square which is 0.143 square.

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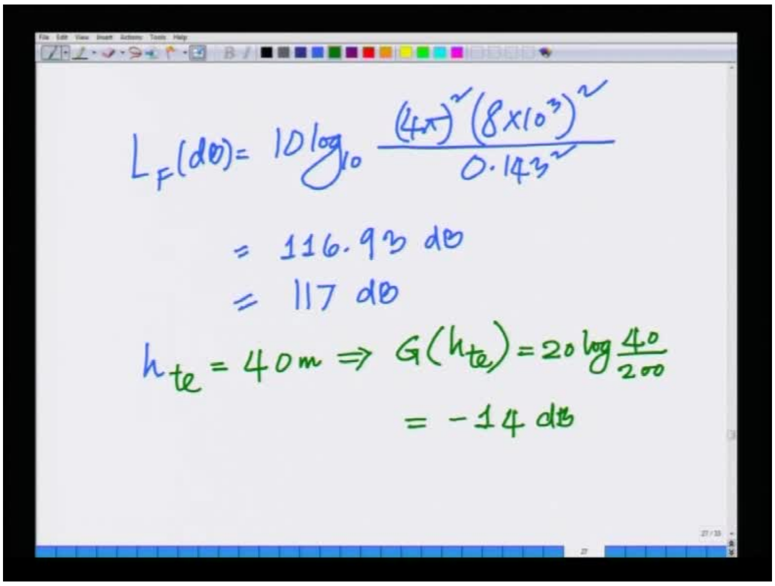

And this is equal to in d B this is nothing but, L F in d B is 10 log 10 of 4 phi square into 8 into ten power 3 square divided by 0.143 square equals 116.93 d B, which is essentially 117 d B alright. So, that is what we are saying is the free space path loss if there is no obstructions, this what path loss would be; obviously, in a city environment we would have a lot of obstructions leading to scattering and reflection.

So, what would the additional factors p first we have to look at the transmit antenna a height gain factor that is that h t e, we are given that the transmit antenna height h t e equals 40 meters implies G of h t e is 20 log 40 divided by 200 equals minus 14 d B and of course, we are going to have again other factor that is a raising, because of the receive antenna height.

So, again due to lack of time here I am going to end this lecture, here and I am going to start covering again complete the rest of the example, and want to a different topic in the next line.

Thank you, thank you very much.