Lecture 35
Wireless Channel

Hello and welcome to NEPTL MOOC, on electromagnetic waves in guided and wireless media. In the previous module, we studied what is called as, 'Transmission Formula', 'Freeze Transmission Formula'. Which tells you, what would be the Bar that is received, at the given receiver antenna, as a function of the distance between the transmitting and receive antennas. Of course, there we did not assume that the transistors had different heights; we assumed the transistors to have same Heights. And whatever the formula that, would that we derived predicted that the Bar at the receiver, would actually change as a function of or is, the change in the Bar is proportional to 1 by D Square, where d is the distance between the two antennas. Right? So, this simple formula which is applicable for free space propagation, when there is no other you know, antennas or obstacles or whatever that, other things are in picture, except that there he has a transmit antenna and receive antenna is sufficient, for us to understand how the Bar would actually fall off, unfortunately when you try to apply the same formula in a real environment, maybe these antennas are there, in the form of a wireless communication, as part of the wireless communication, one of the antennas could be the base station antenna, located on a tower somewhere, at a height and having no, mobile receiver moving with a certain velocity in a given direction or any direction for that matter. And there is an antenna, at the top of that mobile receiver as well, with given certain height. Right? And in a real environment, there are trees which are there, then there are other vehicles, there are humans walking, there could be some river bodies, even the medium that you think of, will not be the same during summer, during winter, you can have forgive winter. And these other you know, I mean, you can have rain, during the rainy season.

So, all these essentially mean that, the energy or the Bar, at the receiver, which is at a certain distance D from the transmitter, you can expect it not to fall off as one by d square, but all these other things, should contribute and change the rate at which or change the no relationship between, the transmit and receive Bars. Right? And that is precisely, what we want to deal with the next few modules here? We start with the simple model of a wireless channel, by wireless channel we simply mean that there is no connecting media between the transmitter and receiver antennas and it is free for all you know, like it's a real world scenario. And for the case that, it is a real world scenario, we are going to assume that the transmitter is located at a height h1 and the receiver is located at a height h2. And what we are very interested is to find out, what would be the received signal bar, at the receiver antenna, as we move away from the transmitting or a base station antenna. Okay? So, this particular information is very important. Because, the received bar at the receiver antenna; will in turn be you know, at the output terminals of the antenna, show up as the voltage across the output terminals. And that, voltage will be amplified and processed further, to extract any information that might possibly be present in the electromagnetic wave, remember that when a user tries to communicate to the base station or the base station tries to communicate to the user, they do so without having any wire in between connecting them. Right? That is the reason why we have a mobile or a wireless communication system. And the information whatever that needs to be communicated between these two, user and the base station or between multiple users amongst themselves or users and base station or between base station to another base station of a different cell, all this have to be done, kind of a wireless communication scenario, except that the base stations are themselves connected by optical fibers for you know, more reliability and faster propagation. Apart from that, the mobile part of it comes when the users are moving away, they are moving over from one region, of the country to another region of the country, in all those cases you are actually looking for, wireless communications. And in, in this wireless communication as I told you, information is carried by the electromagnetic waves and it is important to understand how these electromagnetic waves behave in the real world, what kind of attenuation mechanisms exist in the real world? That will cause in addition to this propagation loss, which is one by d square are there any type of additional losses that, you are going to get and additional distortions of the e/m waves that could be possible, which all of this in turn tells you how much the information could be extracted, what could be the information extraction, efficiency of this system? This is usually measured in the form of you know, when you use digital modulation at the transmitter and you measure this, in the form of a metric called as, ‘Bit Error Rate’. So, the goal including the transmitter to the receiver end, would be to minimize the bit error rate as much as possible and one of the key, ingredients for this is to understand how this electromagnetic wave, as emitted by the transmit antenna, would propagate and we received at the receiving antenna. Obviously that problem is very difficult, very complicated and we cannot even begin to do justice, to the entire you know, area of wireless channel modeling or Wireless channel propagation, simply because it is quite a complicated subject. However, we will consider some very simple models, which bring out the essence of the ideas involved and leave this, more complicated areas, to some other course. Okay? So, our goal would be to first start with phase transmission formula, quickly realized that, that cannot be sustained, as you know as you can see that cannot be correct or that cannot be the complete picture, as you will see from the measurements that have been taken place and from there to see, what additional mechanisms that you know, caused these changes from the predicted freeze transmission formula. Right? To review, what is freeze transmission formula?

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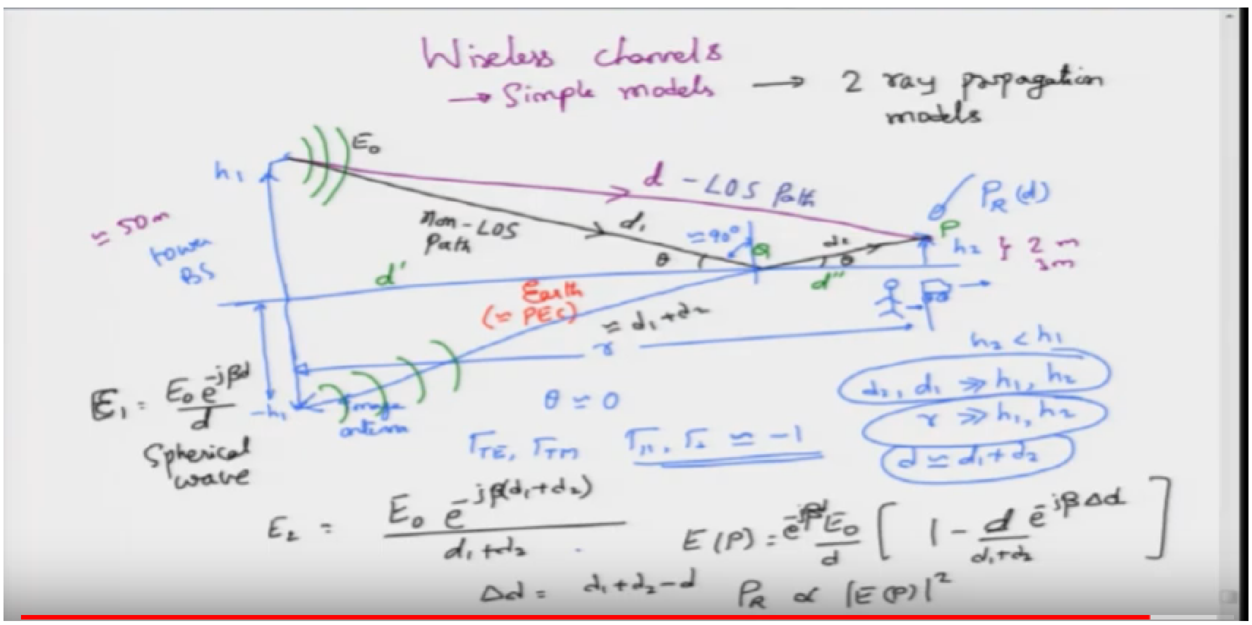

We have a transmitter kept at a height h1, okay from the ground. And then, you have a receiver antenna, with a height h2, which is usually smaller. Like this comes from a tower for example, in the base station antennas and this would be some vehicle which is moving. Okay? As the vehicle moves, the height of the vehicle is actually much, much smaller compared to the tower base station, alternatively it could be a human moving and this is you know, this is another communication the height of a human is, not very high compared to the tower and over which the base station antenna is located. Okay? So, let's locate this antenna here and locate this antenna here. The distance between these two, we will consider this to be D or rather sorry, we'll consider this to be R, for the reason I will tell you later on, so we'll consider this distance to be R and then, we want to understand, what would be the Bar that we are going to receive, at this transmitter sorry, at this receiver which of course, will be at a distance D from the transmitter. Right? Well what is this distance D? Remember this is the transmit antenna, it would be emitting waves and some portion of the waves, of course I have to orient the directions, here I have not shown that the directions are kind of correct, but let us assume that, the directions are actually in the same direction as the transmitting antenna, this is what we assumed even when we did the free space, freeze transmission formula. So, the basic idea is that the transmitter would have, you know, generated on the antenna terminals a current, which is time varying and this current would in turn generate radiation and this radiation would now be propagating towards the receive antenna for, for the case that we are looking at, let us keep the receive antenna fixed, at a particular position, as it moves the, the additional phase shift that you are going to get, because of what is called as, 'Doppler Effect', will in turn result in the fluctuations of the signal envelope, that particular portion since it is not too concerned, with you know wireless or electromagnetic wave propagation, we will not discuss it in detail, we will keep it to a separate course. However what we are going to discuss now, should give you the basic idea, of the loss mechanisms. Right?

So, with that goal in mind, we have these waves which are emitted, I am showing you some spherical waves here, the traditional approximation that people use or an assumption that people use, when they do this Wireless channel model is to assume that, the transmit antenna to be an Omni directional antenna, meaning that, it does not matter where the receiver is oriented, because the transmitter will radiate equally in all directions. Now, obviously that is not a correct assumption to make, simply because you don't want an Omni directional antennas and moreover you cannot get an Omni directional antenna. Right? So, all antennas will have some gain G, which is like a function of theta and Phi, which are the spherical coordinate that, you are as that spherical coordinates, added at the receiver antenna, as well as, the receiver antenna itself, will have a certain receive pattern G R. Okay? So, we are not going to explicitly put theta and Phi in our equations, but it is assumed that someone has to sit down and work out, this gain patterns and then, ask the equations are developed, they will be valid only for a certain theta and Phi, where the values of the transmit antenna and the receive antenna gains, will be denoted by G T and G R. If theta and Phi change that is if the position of the receiver antenna changes or the transmitter antenna changes, then one has to reevaluate this expression, to understand how the Bar would be lost. Okay? So, with that in mind Omni directional is an assumption that we are making, it is not true in general that, I mean, it's not true in real-world scenario, because Omni directional antennas do not exist. Right? On this Omni directional assumption is also called as, 'Point Source Assumption'. And as, I have told you point source assumptions are not really, realistic to begin with, in any case we will assume that this is what we have? We have taken the antenna here and then, the electric field that would be incident on the receiver antenna; this is not a very nice line. So, let me draw the correct line here perhaps, so this line that we have drawn; will have a certain length D. Okay?

Which is actually the distance between the transmitter and the receiver antennas, it is not R. Okay? The reason why this is so is simply because, you are always counting from the source, to the field point which on this case, which in this case happens to be the, receiving antenna h2 that would determine, how the electric field would have, been you know, the received rather than, this other direction are, which is not really the distance between h1 and h2. But, which is Mantle's of concern for the waves, but it is rather the distance, horizontal distance between the two, you know towers maybe if you think of the tower, as well as the mobile unit. Okay? So, that's the difference between D and R is something that you should keep in mind. Of course, this distance R would be equal to D, provided that your H 1 and H 2 would be equal to 0, meaning the transmitters are located so ground I mean, on the ground itself and in that case, you don't really need to worry about, you know the, the, the, the fact that the distance from the transmit antenna, to the receive antenna is different from this horizontal distance R. Right? In that case, both of them will be equal to each other. But, we do know that in practice, tower antennas are I mean, base station antennas are not located on the ground, but they are located at a tower, which is you know the height could be quite a bit. So, it could be about 50 meters or in some cases about 100 meters and so on. But, as the max height here, could be about limited to 2 meters you know, a car or a person or something else, about 2 to 3 meters is a good assumption that one can make. Okay? Well these are all just typical numbers, they are not exact numbers. The exact numbers depend on the application that you are looking at or the scenario that you're looking. Right?

So, you your tower may be 60 meters or your height may be 5 meters, you have to make those adjustments to the theory that we are developing. Okay? So, these pericle waves, which are coming from a point source assumption, would actually travel a distance of D and be received at, the receiving antenna h2. Okay? If there was no other considerations in the game, then this kind of a you know, reception could simply have been predicted, by or could be understood, by our freeze transmission formula, which tells you that, the received Bar at a distance D from the transmit antenna that is, the D that I have taken and let me also call this d, for the path that we have taken as L OS path. LO S stands for line of sight communication, meaning that, these two antennas are seeing each other. Okay? Their orientations are such a way that, they are oriented in the same direction, so that the electromagnetic waves are propagating in what is called as a, 'Line of Sight Communication'. So, in that line of sight communication, when there is nothing else in the universe, in the ideal scenario. So let's write this as, P R in an ideal D that would be equal to PT, GT,G R, where these are all your usual, you know suspects like the transmit Bar, the transmit antenna gain, the receive antenna gain, divided into multiplied by lambda by 4 pi D whole Square. And if you look at, the proportionality constant it is actually inversely proportional to d square, meaning that, it is the distance square as the Bar would go, of course this Bar would be converted into the antenna, voltage V a and then u it will be delivered via, some set a impedance to the load Z L and that is something that you will have to calculate for yourself. Okay? So, this is what you're going to get in an ideal scenario and when you conjugate match the antenna, as we have discussed earlier, then you can actually have maximum Bar extracted from this antenna. Okay? So, this is the scenario for the ideal case. But, unfortunately life is not ideal, because what is this horizontal distance that is connecting between these two? This happens to be earth, okay. Which for our assumption, can be taken to be a perfect electric conductor, the effect of earth being not a perfect electric conductor is very complicated to understand and that is something done, in an advanced electromagnetic analysis of wave propagation, which we will safely leave it to a different course. Okay?

So, what is the effect of this earth? And first of all, what is the effect of this one. Let's actually look at this, this is not the only way one can actually receive, electromagnetic wave from the transmitter to the receiving antenna, why because, these spherical wave fronts, you know eventually intersect at some point with earth, meaning that, there is actually a distance or rather there is actually another path. Okay? We'll call this distance to be some d1 and then, this fellow to be d2, which occurs at an angle theta and this angle is also assumed to be the same angle theta, please note here that, theta is the angle as measured with the horizontal or the earth and it is not the angle measure with respect to the normal, as you would normally do it in the case of reflection. So, this path that you have that, I have shown in black is called as, 'The Non LOS Path' Or 'The Indirect Path'. Okay? The indirect path exists because of these wave fronts intersecting with earth and from there; they will actually be transmitted onto the receiving antenna. Because, earth would reflect, the electromagnetic waves which are incident on it, because it's kind of assumed to be a perfect conductor and from there, whatever the distance d2 that exists, would be traveled by an additional, by another e/m wave. Okay? So, this kind of a path, which is non LOS path, will also contribute to some electromagnetic wave, at the receiving antenna. Okay? We will now, limit ourselves only to these two rays. Okay? So, this is called as a, 'Two Ray Propagation Model', we limit this one to only two rays because, of the simplicity, we want some expressions to come out, but if you were to do this, you know more practical scenario, in a company which deals with Wireless channel modeling, then you would have to use, what is called as ray tracing, where you will assume more than two rays, you will assume many, many rays and propagate each of those Ray's.

Again, the fact that you are using race, instead of waves, you know, although some wave nature is involved is simply because of these assumptions that, we have made a point source, a nice plane wave front, know these are the assumptions that we have made and we have also assumed, without telling you that we are dealing with the far field of the antenna. Okay? These assumptions are not so evident in many communication textbooks, but when you look at propagation textbooks, you will actually see this one and literature of course, you know left there is abundant literature, which actually clarifies a lot of these points that we are making. Okay? So, this is our basic idea, what we are interested is to now look at the received Bar, in the non ideal scenario of to raise, one following the line of sight communication, a LOS and the other being the non LOS path. Okay? So, let us look at this, the electric field from the LOS path, can be written as say, e 1 and this E1, so let's write it as E1, can be written as, whatever some constant that, we will have which we will call as, 'E0'. And then you have e Bar minus J beta D divided by D. Okay? So, this would be the initial amplitude e 0 which I have simply assumed. So this is, the beta is 2 pi by lambda, which we had also called as,' K' in the earlier modules. But, now we are calling this as beta, so this e 0 e Bar minus J beta divided by D is the spherical wave that we have assumed, with the face that you are going to get, which is beta D is the face that you have and this inverse, know amplitude means that, we are actually dealing with the far field, remember antennas have near fields and far fields and in the far field, this electric field would be propagating as 1 over R, you know e Bar minus JK r by r was the, you know plane wave that we considered, so this was the face of the spherical wave. And it's important that, we are dealing with the case, of far field.

Because, in near field the fields actually grow as 1 over R square and 1 over R cube, moreover I am dealing with electric field, so you do know that, even for a short dipole the electric field, actually has two components theta and R, however in the far field the R component can be neglected, H is of course a single component along Phi, the reason you want, H along Phi and along theta is so that, E cross theta or rather E cross H, should point or take away energy in the direction of the radial thing. Okay? So this is the electric field that you are going to get, because of the direct or the LOS path. Now, how about the non LOS path? Let's also introduce couple of additional, note a I mean additional points here, so I have D prime, as the distance and D double prime, as the distance from the point, which we will call as, 'Q'. Let us call this as, point 'P'. So, from the point P where there is reflection, the distance, the horizontal distance to the receiving antennas D double Prime and this is D Prime. Okay? Now, let me show you some typical assumptions that we are going to make, which are very important, for getting some simple analytical formulas. Okay? So, we are going to make a few assumptions, these are really important assumptions that we are going to make, which will simplify our calculations. So, as before the horizontal distance is R there is okay, no problem. But, what we are going to assume is that, the distance d1 is much, much larger compared to the height h1 and R is assumed to be much, much larger than both h1 and h2, D 1 as well as D 2 we will assume it to be much larger than H 1, as well as H 2 ,we would also assume H 2 to be less than H 1, although there is no real reason, why we are doing it, but sorry, there is a reason why we are doing it that is because you know of the typical application, but if the height is not negligible, then you'll have to do more complicated analysis, where your height H 2 will also be, quite high. Now, the Assumption will, will also assume that D is of the same order, as d1 plus d2, not quite equal but of the same order. Okay? These are important assumptions, in the sense that, they will help us find out what is the electric field, at the point P. Because, of this non LOS path. Okay? What is this field going to be with all these assumptions, the fact that we have assumed R to be much larger than H 1 and H 2, there was Jim D 1 and D 2 also to be much larger as, is d to be much larger than H 1 and H 2 .The angle theta will almost be equal to 0 .okay? So, it's like you have to imagine this, you know you take some 50 meters here and then take some, you know 2 meters on this side, but then the distance between them, would be a few kilometers. Okay? So, you imagine that there is a 1 kilometer distance between transmit and receive antennas, with the transmit antenna sitting at 50 meters, while the receiving antenna is sitting at 2 meters, but the distance between them is 1 kilometer. Okay?

So, if you actually do this you know, you know on a graph paper, you we see that this angle theta is almost equal to 0. And when theta is almost equal to 0; that means, the angle of incidence, sorry, the angle of incidence that we consider, would actually be, almost 90 degrees. Okay? So, it's almost like perfect conductor. And for this case both the TE, as well as the TM or as in wireless communications, we call it as, both parallel, as well as perpendicular incidences, the electrics sorry, the reflection coefficient of both of them, will be approximately minus one. Okay? This is almost like, you know incident in a wave in a normal kind of a thing or what is called as, grazing angle to the interface? And in that grazing angle to the interface, both the reflection coefficients for the horizontal polarization, as well as for the perpendicular polarization, the reflection coefficient will be approximately minus 1. Now that minus 1 implies earth is being considered as a perfect electric conductor, because any wave that is incident on a perfect electric conductor would come back, with a phase change of Pi. Okay? So that is what our assumption of perfect electric conductor comes from, with a grazing angle incidence, gamma of both horizontal and vertical polarizations are approximately minus 1. Okay?

So, this is an important part, because now the electric field, no sorry, that will actually allow us, to use what is called as, 'An Image Theory'. Okay? Image theory means that, you can consider the propagation of the non LOS path, as having originated from another antenna, which we will call as the, 'Image Antenna', located exactly the same height, you know as the transmit antenna, which of course in the earth or in the surface below the earth, okay. This kind of an image is possible, when as I have told you in the quarter wave pole discussion or the half wave dipole discussion that, you can treat earth as, perfect electric conductor and whatever the antenna that you put on top, at the same height, there will be an image point, which you can think of it's a fictitious point of course, but this image point is the one that is also, sending out this electric fields. Okay? So, you can replace the non LOS path, which goes from d1 to d2, with the path that goes from D, no from the image point all the way to the point P. Okay? So this one will now be, the image radiation that has been, sent out by the image point, with a total distance of roughly d1 plus d2. If you actually do the geometric construction, you will see that this two don't exactly coincide, the image point distance from, the distance from the image to the point P, will be slightly longer than d1 plus d2, however that complication can be ignored, because we have assumed the distances to be so large that this d1 plus d2 is approximately the same, as this d1 plus d2. Okay? So when, with that in mind and the approximation of course, becomes better and better as, the distance between transmitter and receiver are, move far away from each other. Now, what is the electric field because of the image antenna, it would be the same easy E0 amplitude. But now, the distance that you are going to get, will be e Bar minus J beta D 1 by D 2 divided by, the distance D 1 plus D 2. So, this is e 2 and together, E1 plus E 2 will be the overall you know, field that you are going to get, at the point P. So, e at Point P would actually be equal to e 0, into e Bar minus J beta D divided by D minus E Bar minus J beta D 1 plus D 2 divided by D 1 plus D 2. Okay? Where the minus sign comes because of the reflection coefficient being approximately minus 1, Okay? Now, I can put this into a simpler form, I can move the E Bar minus J Beta D by D outside of the integral. Okay? When I do that, I get E 0 by D; there is a phase factor e Bar minus J beta D, 1 minus D divided by D 1 plus D2 right, that's all. So, D divided by D 1 plus D 2. But, in the numerator here, I can replace this D 1 plus D 2 by where Delta D is the path length difference between the non direct, as well as the direct paths. So, D 1 plus D 2 minus D. Okay? This is the expression that you have, if you wish you can pull this D by D 1 by D 2 onto this side, although we have said that D is approximately the same order as D 1 plus D 2, will not make that assumption in this, as yet we will make that assumption later on, to tell you what is going to happen, okay. So this is the electric field, so the received Bar would obviously be proportional to the electric field, magnitude square and in order to do that one, know you just take the magnitude square and in order to perform any further simplification, you need to express this D 1 and D 2 in terms of R, as well as well, we'll keep D as it is and then express everything in terms of R 1 plus I mean, in terms of R. And you have to use some ideas of trigonometry, in order to do that one; I'll give you the basic idea. Okay? I'll reap lot this entire thing,

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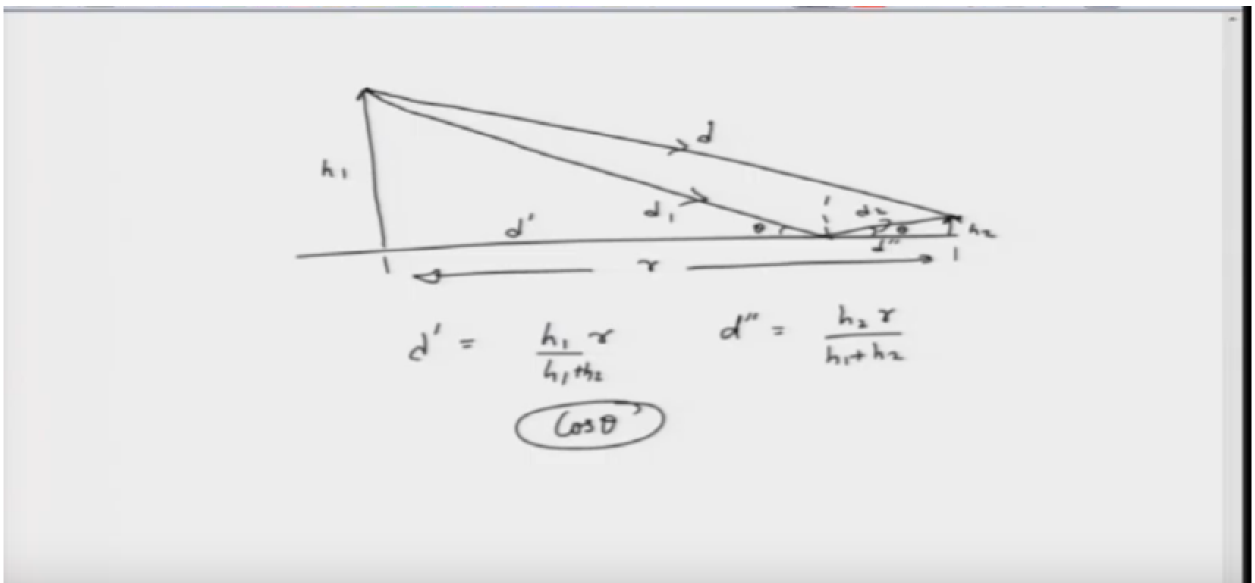

I'll give you the basic idea and we will complete this analysis in the next module. Okay? So this is D and this is D 1 plus D 2 or rather this is d1 and this is d2, both are at the same angle theta. Right? This is Theta, this height is H 2 and this height is H 1. And this distance here is R. okay? And you can use trigonometry to show that, if this angle theta is the same, we had called this as, D Prime and this as; D Prime the horizontal distances. Right? So, if these are the same, then their cosine should also be the same. Right? Cosine of theta of these two should be the same. And using this cosine of the angles between these two as the same, you can show that D prime is H 1 by H 1 plus h 2 into R and you can show that, D double prime as H 2 R by H 1 plus h 2. Okay? So, by showing that, cosine of the angle theta to be the same for these two rays, because they actually make the same angle theta; that is this D 1 and D 2, I raised and then you can show that D Prime and D double Prime the horizontal distances, can be expressed in terms of the antenna Heights h1 h2, as well as, the horizontal distance between the transmitter and Receive antenna. We are going to come back to this equation, because this is very important and then see what kind of the path loss; that we are going to get in the next module.
Thank you very much.