Advanced 3G & 4G Wireless Communication
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Lecture - 38
Link Budget Analyses

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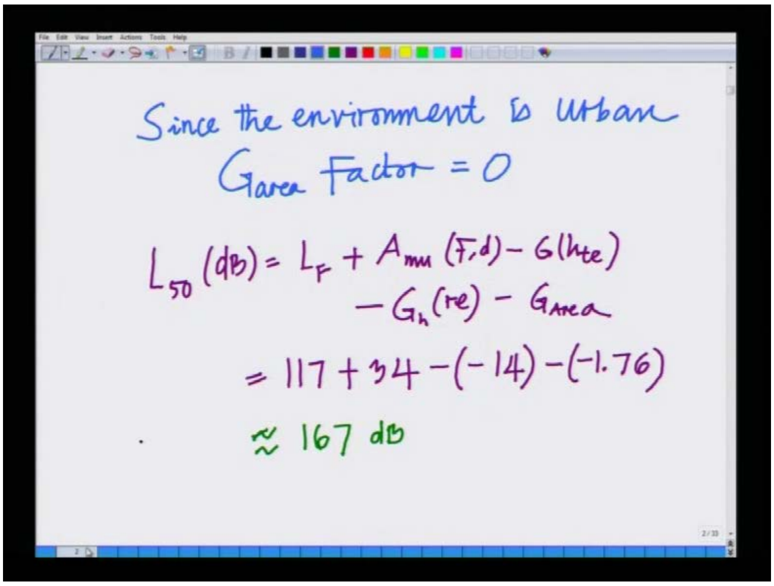

Hello, welcome to the course of 3 G 4 G wireless communication systems. In the last lecture, we rapped up all discussions in the okumura model. And we were looking at the example of the okumura model, and we said that example scenario at a distance of a 8 kilometer carrier frequency 2.1 Giga hertz and other parameter values. The path loss is 167 d B, what is (( )) computed.

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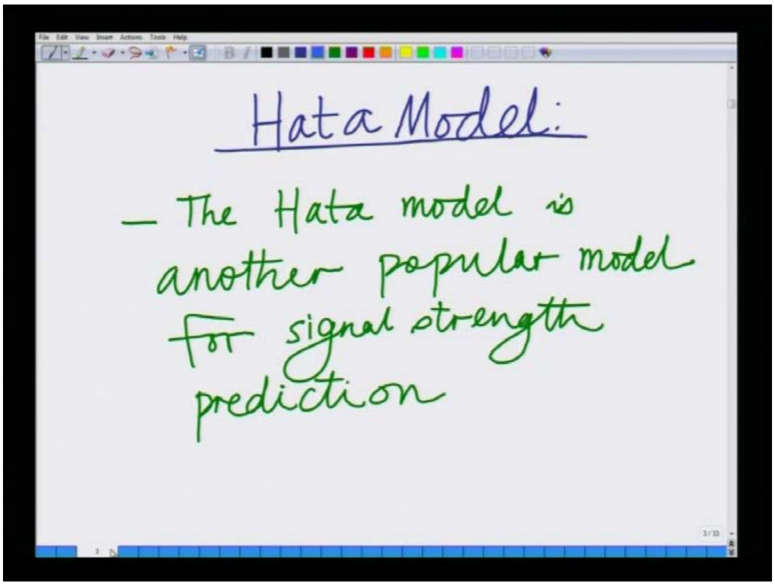

Then we moved on to the hata model, and we said that the hata model is another popular model. Similar to okumura model except, it gives analytical formulation to the graphical okumura model, where the okumura model uses lot of graphs, and so on.

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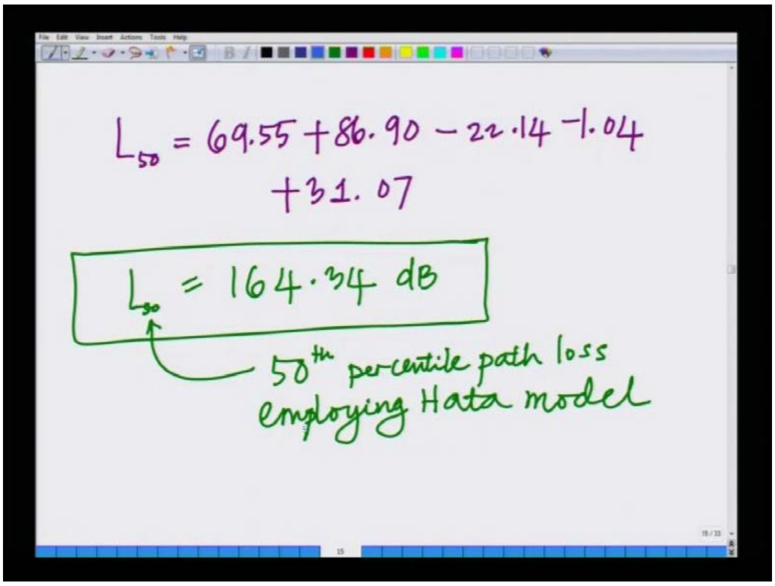

And we said we considered, the same example using the okumura model hata model, and we said the path loss is 165 d B, which essential close to what is predicted by the okumura model.

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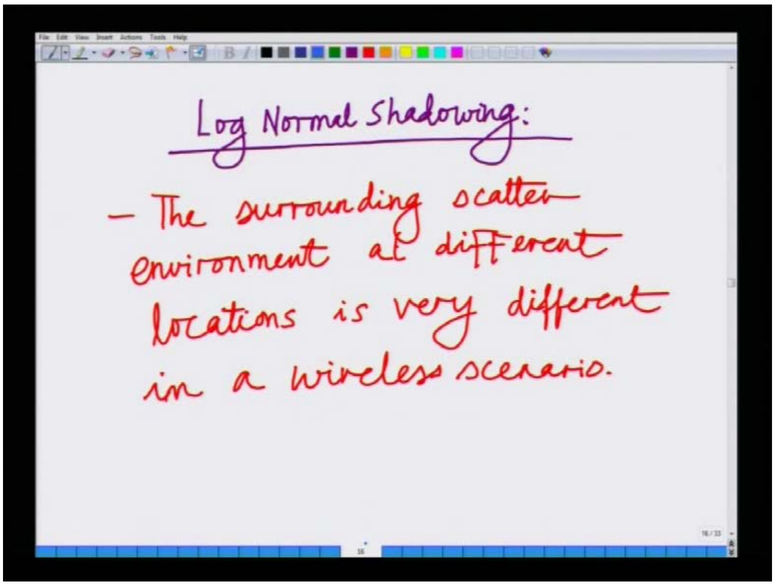

And then we moved on to something more important cellular system, which is the log normal shadowing, we said even at the same distance in several different points in cellular system path loss is not same, because of the shadowing effects.

That is because the user might, the mobile user might present be behind, large wall, large building or an abstraction is shown, hence the shadowing hence the net signals received at a shadowing strength looks like random, it is random in nature with the mean or the 50th percentile of signal strength predicted by the ukumura or hata model. And the essential random deviation, there are random deviation around this mean signal strengths. This is termed as log normal shadowing.

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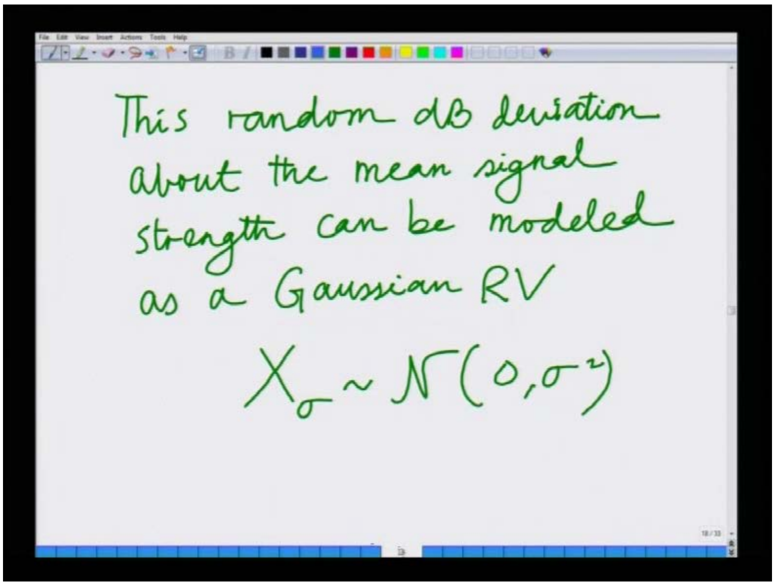

In fact, we said that this factor, which is the log normal shadowing factor, this can be expressed in Gaussian random variable with variant sigma square, it is log normal because this x sigma is in d B, hence logarithm of the power normal, hence this is the log normal random variable.

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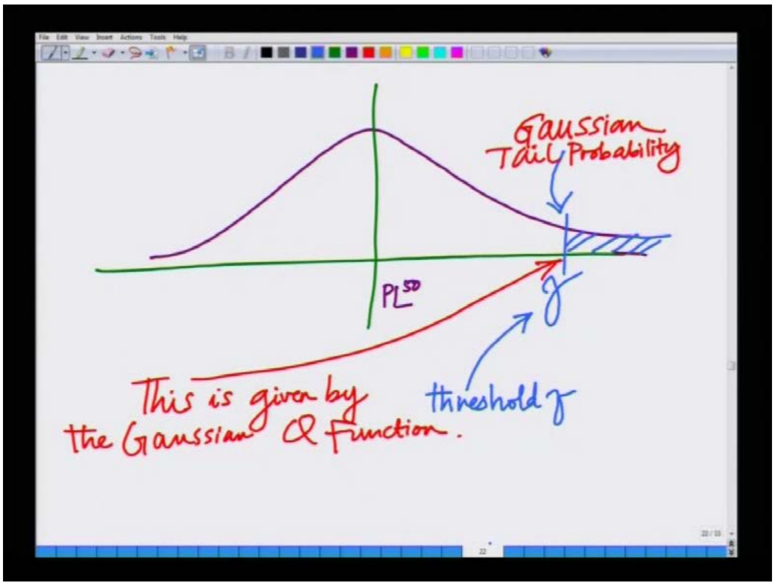

And we also looked at the other important thing, this log normal fading, if I look at the distribution, it looks like a distribution mean with 50th percentile of the mean path loss, and a random spread around this thing, and we said we want to compute the probability, that the path log is greater than certain threshold gamma, and factor use the properties of the Gaussian distribution.

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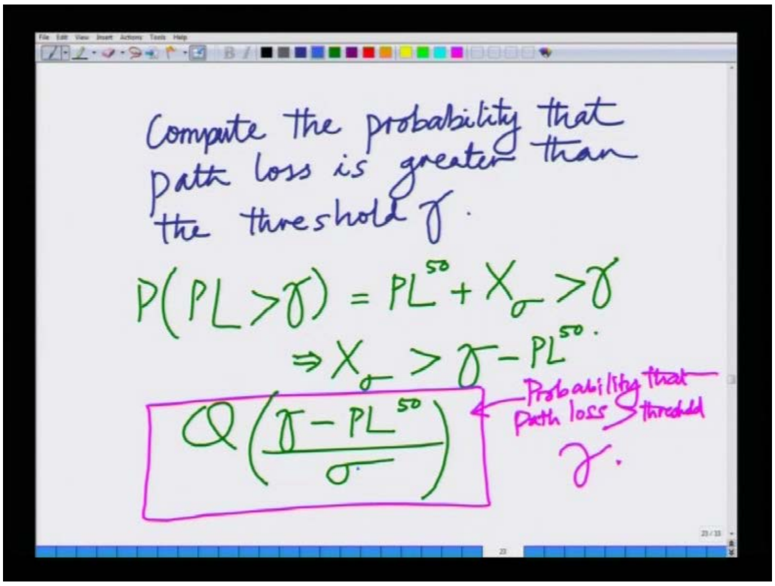

And that is nothing but, path logs mean path logs plus X sigma, which is Gaussian random variable which is 0 with X sigma, which has variant sigma square is greater than gamma, which means X sigma is greater than gamma minus P L 50, and the probability is given by the Gaussian Q function, which is Q of gamma minus P L 20 mean path loss by sigma. This is the probability that, because of log normal shadowing probability, that path loss is greater than this threshold gamma.

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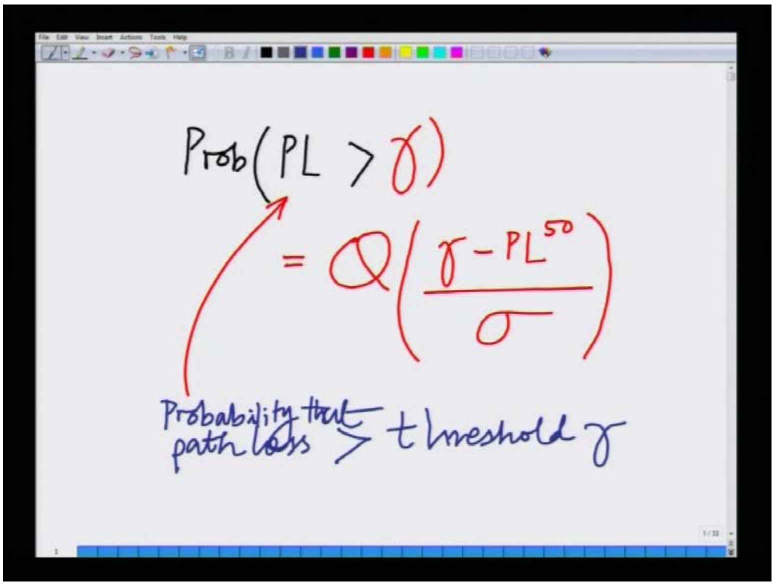

Let us start from here, and continue this discussion. We said that the probability that the path loss the probability that the path loss actual path loss is greater than threshold gamma is nothing but, Q function, that is Q function of gamma minus the path loss divided by sigma. This is the probability that path loss is greater than threshold gamma. Hence, this is the probability, that the path loss is greater than threshold gamma.

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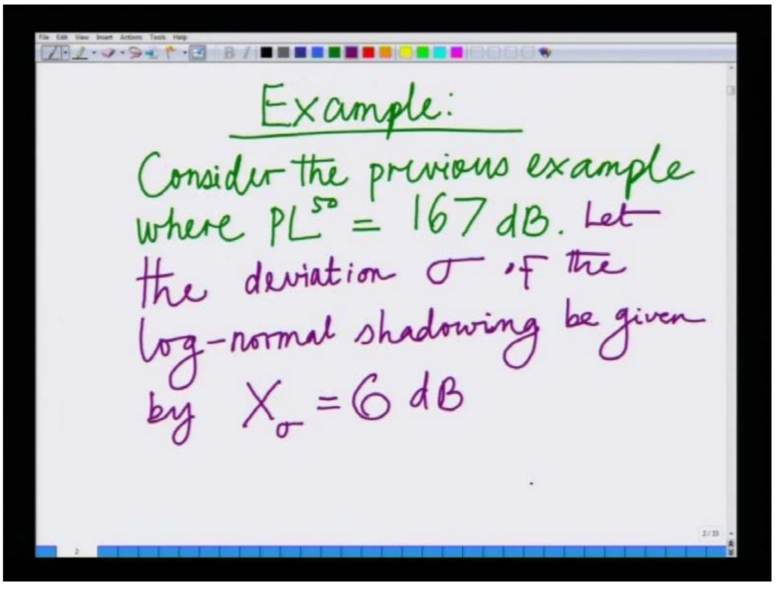

Let us consider an example, let us to understand this better let us consider a example, what I want to consider this example is I want consider the same model, that we are used in the with previous example, that I want to consider previous example consider previous example used in the hata model, where path loss 50th percentile of path loss where the 50th percentile of path loss given as 167 d B.

Now, consider log normal shadowing, let the deviation sigma of the log normal shadowing be given by X sigma equals 6 d B. So, we are considering the log normal Gaussian random variable for the log shadowing with a deviation that is sigma equals 6 d B, because sigma equals 6 d B. That is the deviation of the log normal shadowing factor and we said the 50th percentile path loss is 167 d B.

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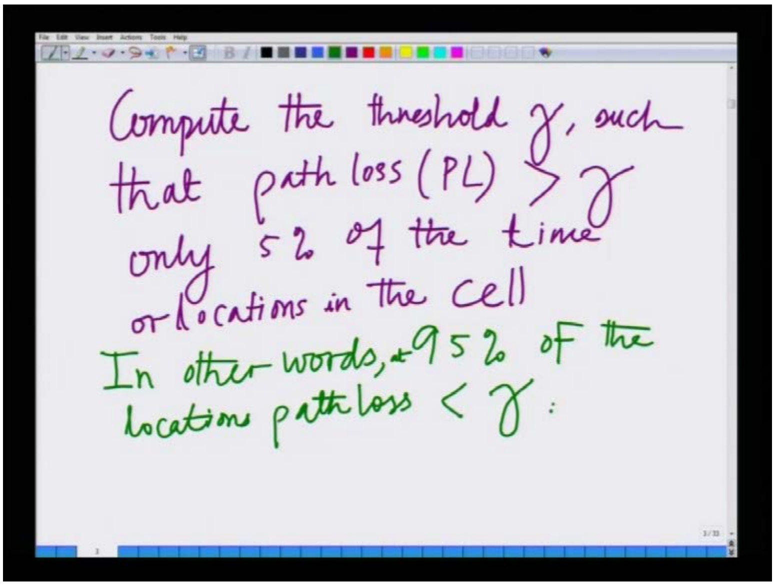

Now, employing these two facts, we would like to compute. Compute the threshold gamma such that path loss is greater than gamma only 5 percent of time, and the path loss is less than gamma 95 percent of the time. So, what we want to do is we want to compute the threshold gamma, such that the actual path loss P L is greater than gamma only 5 percent of the time or locations in the cell. Which in other words saying 95 percent of this is lower than threshold gamma. That is to other words 95 percent of at 95 percent of the locations path loss is less than the threshold gamma.

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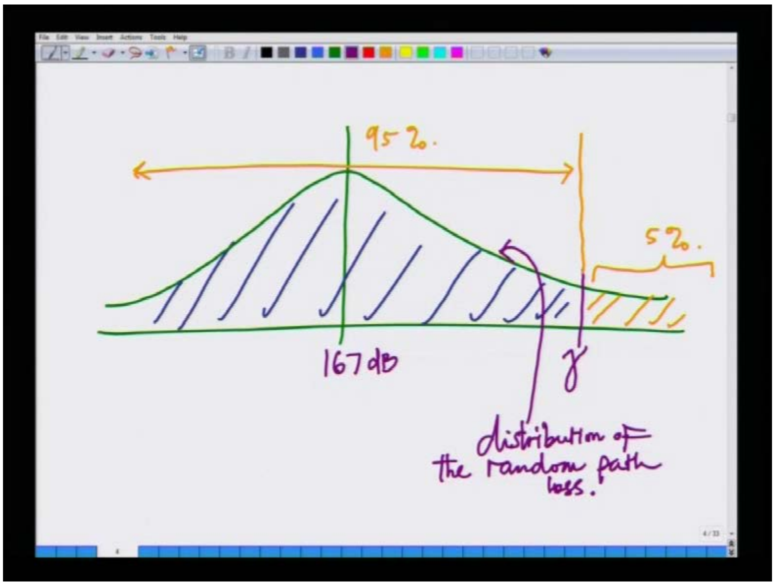

That is we are setting, this as follows we are saying that the distribution looks like this, where the median path loss is 167 d B, that is the median path loss, and we want to compute this threshold gamma, such that most of the time our observed path loss with this probability is less than gamma, and with the small probability, it is greater than and this probability is greater than nothing but, what we were saying 5 percent, and 95 percent of the time it is less than this threshold gamma.

So, if I work out that draw this 95 percent of the time, it is less than gamma and only 5 percent of time, it is greater than gamma, because this is the path loss, which is the random variable. And this is the distribution of that random path loss, this is the distribution of the random path loss, this is the distribution of that random path loss.

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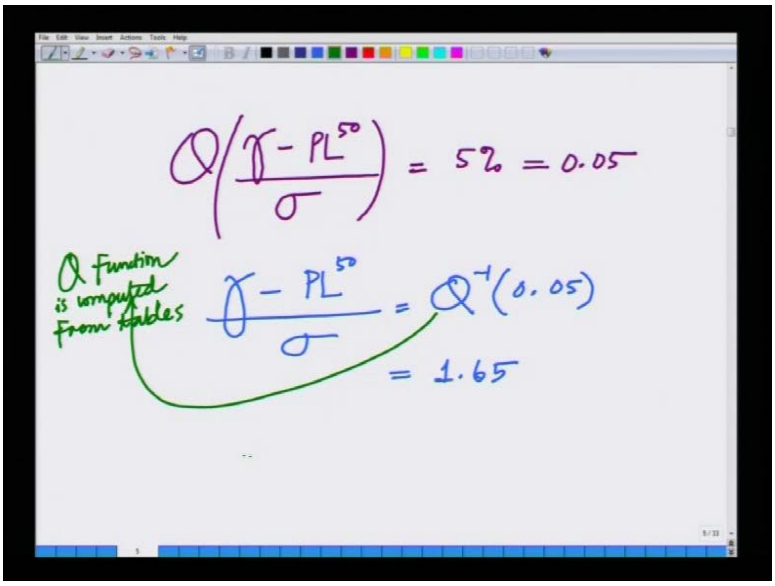

Hence, what we have derived in our earlier discussions, we said that this probability, that the path loss is greater than gamma is nothing but, Q function of gamma minus the 50 percent path loss by sigma equals 5 percent, that is threshold is 5 percent, which essentially 0.05, which essentially also implies that gamma minus the 50th percent of path loss by sigma equals Q inverse 0.05, which is essentially 1.65.

This Q function is the value of the Q function is given for different values is tabulated, in the form of tables from those tables, you can read this values for 0.05 alternatively, this can also be computed in mat lab. This G Function can be computed is computed from the tables alright.

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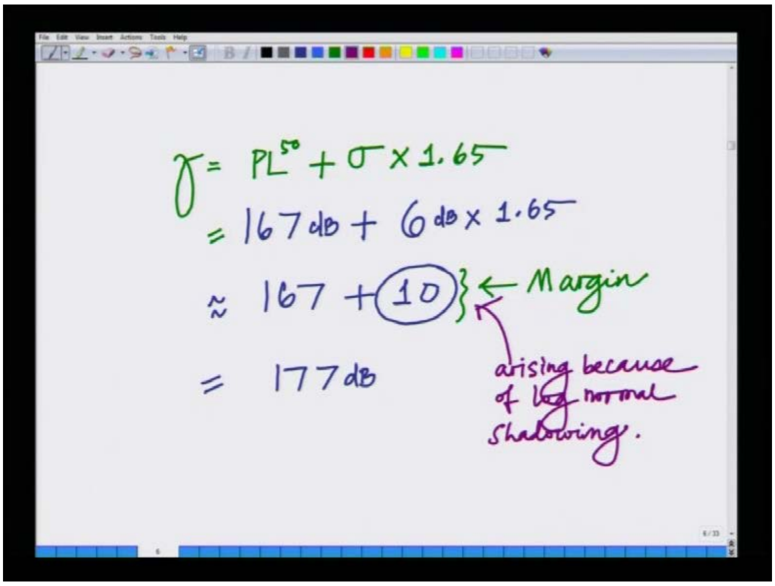

Hence, we can also write from this expression here, we can also write that gamma equals the 50th percentile path loss plus sigma times 1.65. We know both this quantities the 50th percentile path loss is 167 d B plus sigma is given as 6 d B so this is 6 d B tomes 1.65; this is equal to approximately equal to 167 plus 10, which is equal to 177 d B 177 d B.

Hence, it is said that hence what this example; essential is that even though percentile path loss, the 50th percentile path loss is 167 d B, because of the spread or the randomness 50 percent, it is only this is less at 50 percent of the location, it is greater than 167 d B, hence 50 percent of the location it is less than 167 d B. So, if you want that additional reliability, that it is only greater than greater than the certain threshold only 5 percent of time, that threshold is not 167 d B, but 177 d B.

That is you can claim that is if you want to account for your path loss, such that pass loss is greater than threshold only at 5 percent of the locations.

Then you have to transmit an additional 10 d B of power; this is nothing but, this is termed as the margin, where this margin is essentially arising because of the random shadowing factor, arising because of arising in fact because of the of the log normal arising because of the log normal shadowing in the system. Hence, now we can claim that the path loss greater than 177 d B only 5 percent of the times.

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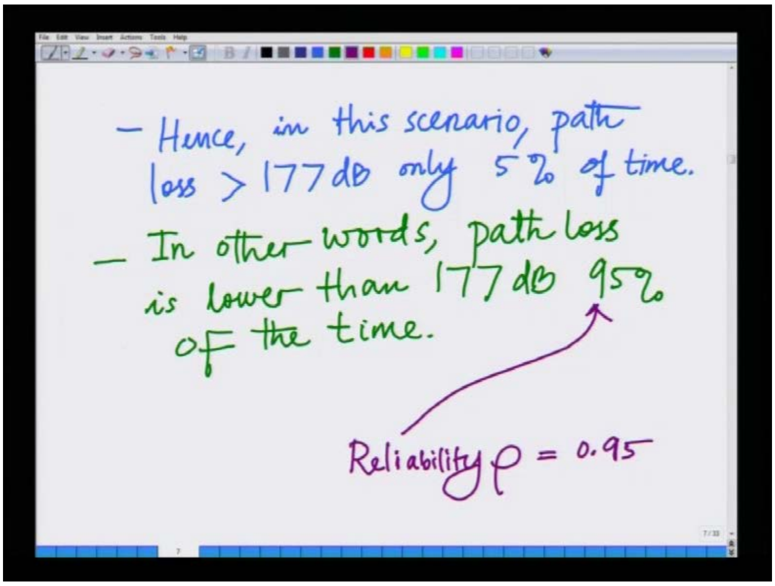

Hence, in this scenario, the path loss is greater than 177 d B only 5 percent of time. Hence the path loss is greater than 177 d B only 5 percent of time. Another way of saying is this is path loss is less than 177 d B 95 percent of time, it is greater 5 percent of time, which means rest of the time is lower, which is same thing as saying 95 percent of time it is lower than 177 d B. Hence, in other words path loss is lower than 177 d B 95 percent of the time. Which means this 95 percent is also nothing but, this is the reliability row, which is equal to 0.95. So, we can say the outage, which is the chance path loss is greater than the 177 d B is 5 percent which 0.05, in other words the reliability. Which is that path loss is less than the threshold 177 d B, which is nothing but, 95 percent or 0.95.

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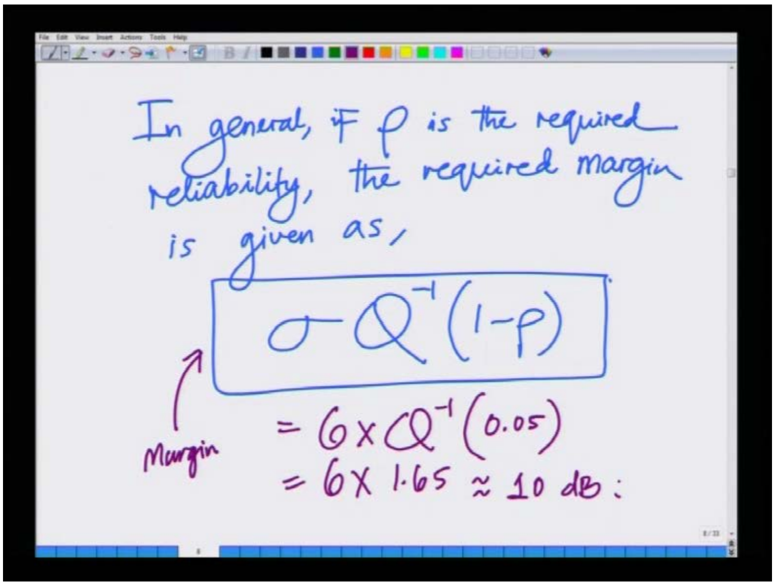

And in terms of reliability the margin required in general in general, if row is the required reliability or the desired reliability, the required margin that desired margin is given as is given as sigma Q inverse 1 minus row; this is the this is the margin. Which in the previous example again I want the same thing this is 6 times Q inverse 1 minus row, row is 0.95, therefore the Q inverse 1 minus row Q inverse 0.05, which is exactly 6 into 1.65 approximately 10 d B.

So, you can think of it two ways either think of it as path loss greater than the certain threshold, or path loss lower than that threshold with 1 minus that the probability. Which essentially nothing but, the reliability two ways to think about it; one is out age, which is path loss greater than the threshold, the other is reliability path loss lesser than that threshold, and the sum of both probability is one essentially.

So that is essentially log normal shadowing aspect of log normal shadowing of this thing, which essentially shows that, if you want to account in the randomness in the shadowing factor around the cell, because of the large objectives that is buildings and walls and large shadowing objects, then you have to transmit an additional power, which essentially nothing but, the accounts of the log normal shadowing and that is also termed as the margins in the cellular system.

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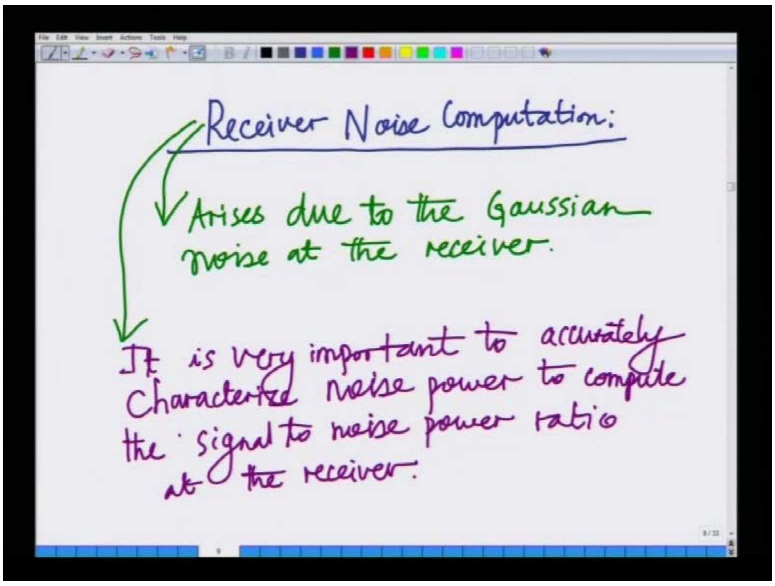

Now we move on to the next topic, which is actually the one of the important parts in this cellular at the cellular receiver, which is essentially characterize the noise process. So, the next aspect, you want to tackle is that the receiver noise computation. Receiver noise is nothing but, the thermal noise that is present at the receiver, this arises due to the thermal noise arises due to the thermal or essentially the Gaussian noise, what this model has Gaussian noise at the receiver and this is the important, this is the one which important essential to characterize noise at the receiver to accurately model, the signal sigma ratio at the receiver.

It is important, it is in fact critically important very important to accurately characterize noise power to compute the signal to noise power ratio, that is the use of this noise power is obvious, because of we want to compute the signaled noise power ratio at the receiver, everything at the receiver, that is accuracy of decoding, and so on. Depends on nothing but, signal ratio of signal power or the noise power, the signal power we can compute from the transmit power path loss, and so on and so forth. the noise power which is remain part as to be characterize accurately to characterize this signal to noise power ratio.

And the expression for this signal noise power ratio, this is given first characterized into two steps; first is known as noise power spectral density.

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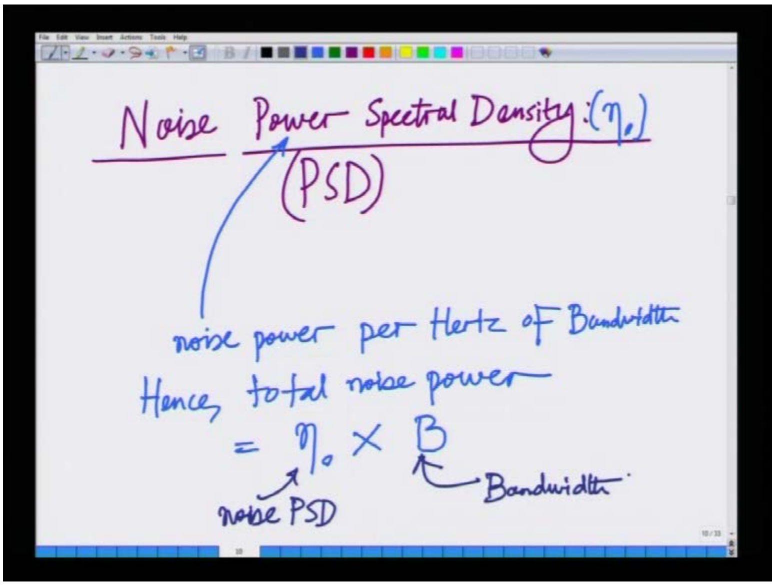
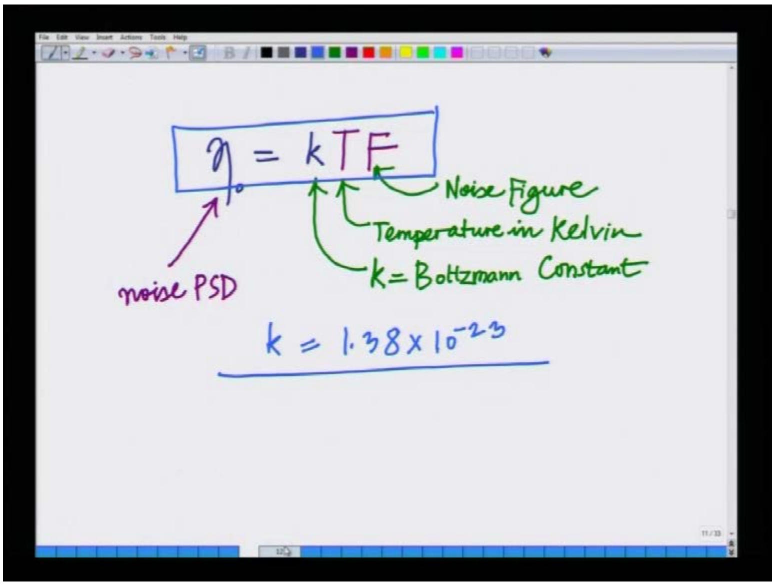


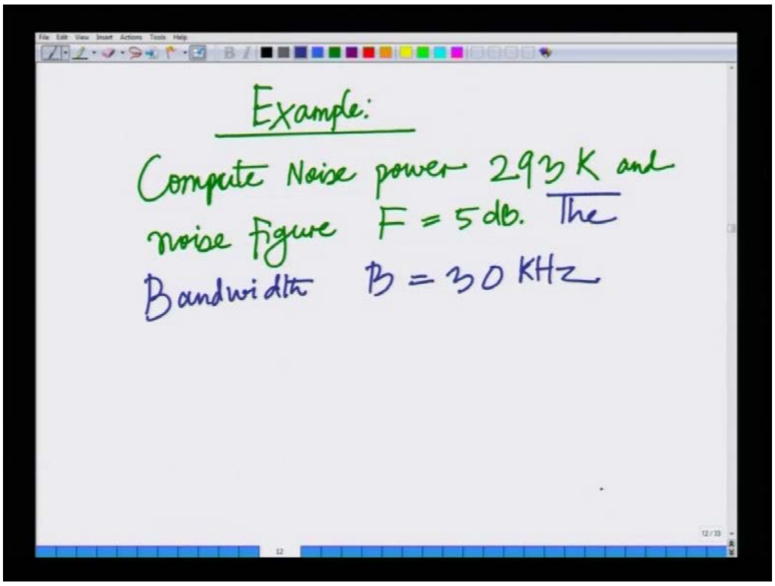
The noise this is the noise power spectral density this is simple abbreviated as PSD, which as the name suggest means essentially that what is the density of the noise per hertz, this is nothing but, the noise power per hertz of bandwidth. Hence naturally if this noise power spectral density denoted by eta, total noise power this is noise power per hertz total noise is nothing but, the this density into the total bandwidth B.

Hence total noise power equals eta naught into B, where eta naught is the noise power spectral density, and B is the eta naught is the noise power spectral density and B is the bandwidth of the system, knowing the noise spectral density, and bandwidth of the system. I can compute the total noise power. (Refer Slide Time: 21:40)



And the noise power spectral density expressions for noise power spectral density expressions, eta naught is given as follows nothing but, k T F where of course, the left is noise power spectral density, what I have on the right first k, which is equals to the Boltzmann constant strength then I have T, which is nothing but, the temperatures in Kelvin, and I have F. Which is essentially nothing but, the noise figure, this is the noise figure.

Hence, this is the net standard density for the noise power spectral density, which is essentially eta naught. The noise power spectral density nothing but, k T f; the k is the Boltzmann constant strength, and T is the temperature in Kelvin, and f is the noise figure. And this k has the standard value that is Boltzmann constant, which is essentially 1.38 into 10 to the power minus 23; this is value of the Boltzmann constant. (Refer Slide Time: 23:18)



For instance, let us consider this example let us now consider this example; compute noise power at 293, compute the noise power at a temperature of 293 Kelvin, and noise figure F equals 5 d B F equals 5 d B. Also the bandwidth the bandwidth B is equal to what we asked to do is we are essentially asked to compute the total noise power, in this system, where the bandwidth is 30 kHz F is 5 d B, and the temperature is 293 Kelvin. This we have to proceed in two steps; first we have to eta naught, which is the power spectral density multiply, this noise power spectral density by the bandwidth to get the total noise power.

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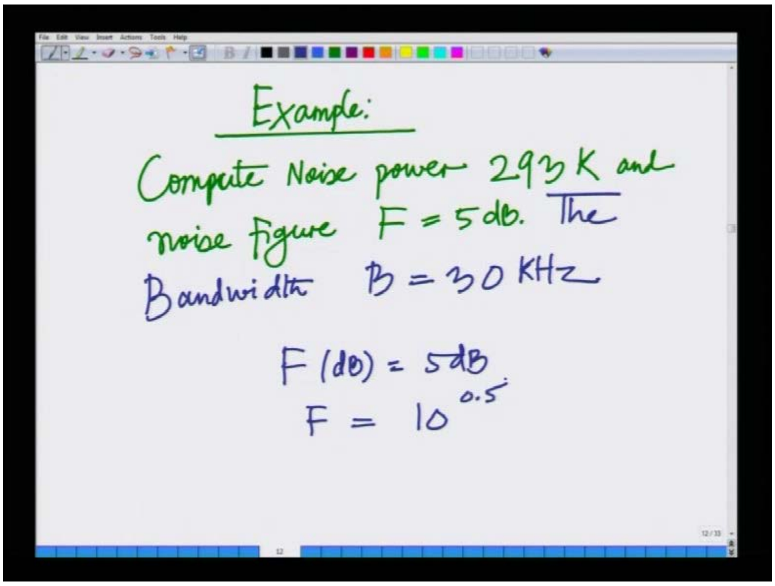

Hence, what we have here is eta naught, first let us compute F in d B F in d B equals 5 d B, which means F is nothing but, 10 to the power of 0.5 in linear values.

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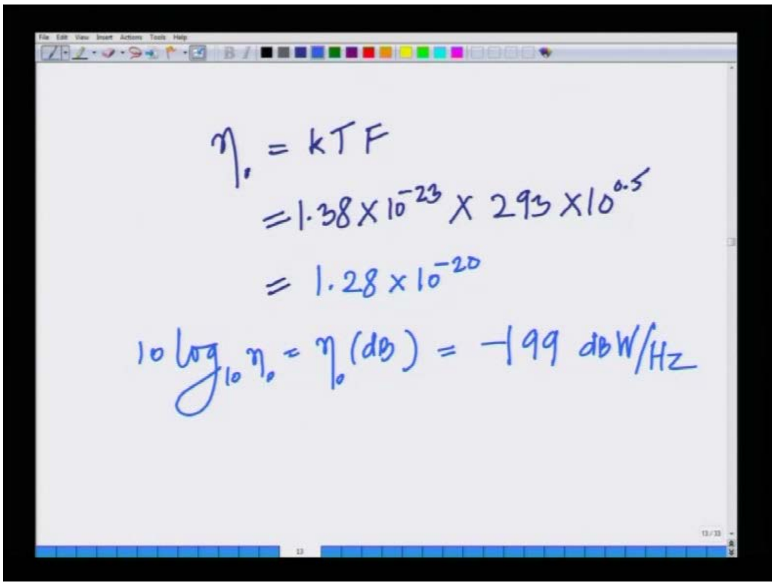

Hence, remember eta naught equals k T F, k is Boltzmann constant, which is 1.38 into 10 to the power minus 23 into the temperature in Kelvin, which is 293 Kelvin into the noise figure 10 to the power minus 10 to the power 0.5. This is k, this is t, this is f and this product we can show is given as 1.28 into 10 to the power minus 20.

Hence, log 10 10 log 10 eta is nothing but, noise prospect to density in d B, which is nothing but, minus 199 and this is in d B watt per hertz, remember this is power spectral density. So this has to be watts per hertz, further we are in d B. So, this is d B watts per hertz that is that is minus 199 d B watts per hertz.

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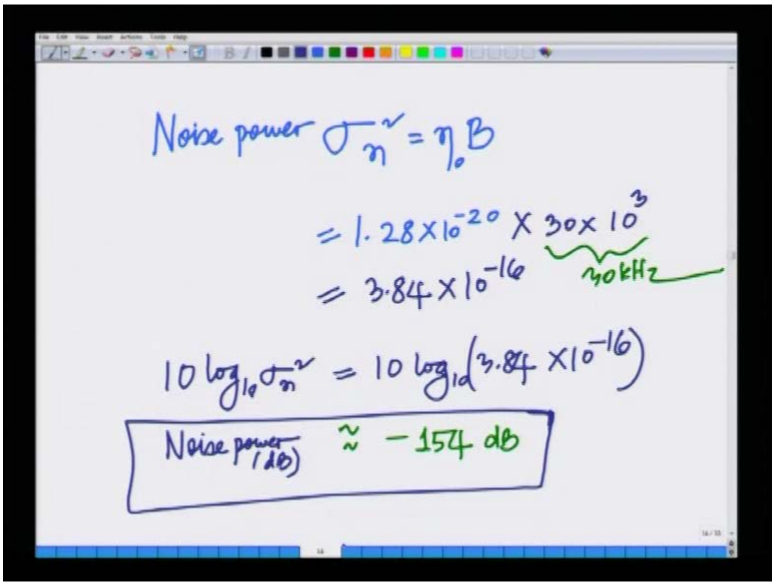

And now we also said that the noise power sigma n square equals eta naught into B, which is essentially 1.28 into 10 power minus 20, this is said eta naught into 30 into 10 power 3, equals 3.84 into 10 power minus 16. Hence, 10 log 10 sigma n square 10 log 10 sigma n square equals log 10 84 into 10 power minus 16, approximately equals to minus 154 d B. Hence, noise power in this scenario is eta naught B, where eta naught is this 1.28 into 10 power minus 20 B is 30 kilo hertz, that is 30 into 10 power 3; this is nothing but, the 30 kilo hertz bandwidth, and the net noise is 3.84 10 power minus 16, convert this into d B value, that is minus 154 d B.

Hence, this is nothing but this is nothing but, the noise power in d B, so the noise power in d B. So, what we are saying is minus 154d B, thus we have computed the noise power in d B.

So, you have computed several aspects, we looked at path loss, we looked at 50th percentile path loss. We looked at margin required for log normal shadowing; we have looked at the receiver noise log normal shadowing. Now, we have to put all these aspects into that is known as, the link budget analysis, that is we have to budget for different losses, and gains, and different parts of the wireless communication system, this system does the link budget analysis.

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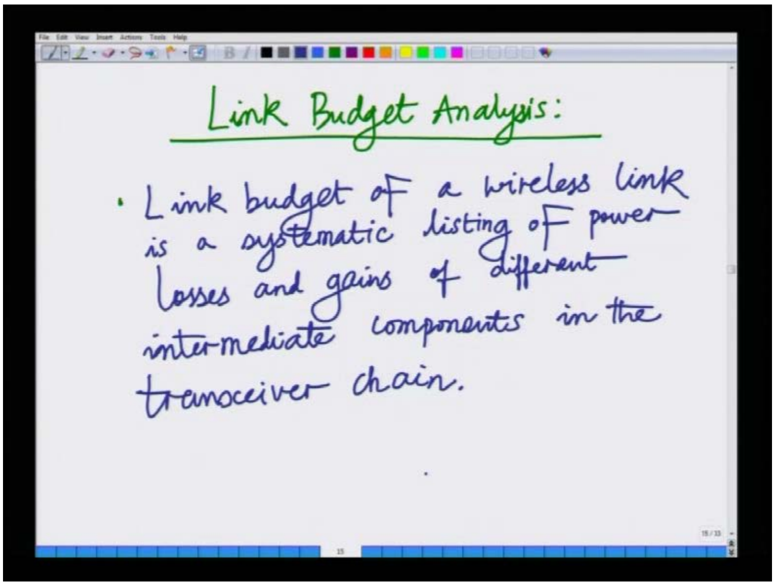

So, the link, so the next topic, we are going to discuss is the link budget analysis. And link budget analysis, we said is nothing but is a budgeting of power for different aspects of wireless communication system. So, link budget analysis, in fact link budget of a wireless link is nothing but, the systematic is it is a nothing but, the systematic listing of the power losses of power losses, and gains of different intermediate components of different intermediate components in the…

So, link budget analysis is nothing like a budget it is the systematic listing of different components and their associated power gains and losses in the whole of this the transceivers, that is from transmitter to the receiver, so that you can account more the power gains and the losses. So, that you know how much transmitter is transmitted, how much transmit power is received, and what needs to be done. It is like the budget analysis for this link, all right.

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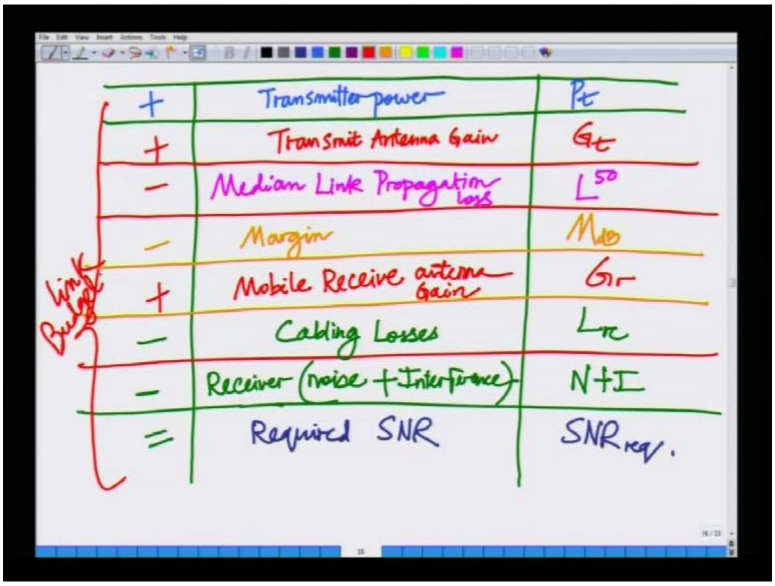

And so, let us list, this different components now. So, I am going to write this as the table as follows as I am going to draw a table, in this table I am going to first write its sign. If it is a gain or a loss for instance transmitter power, the transmitter power is a gain. That is larger than the transmitter larger than the transmitter for larger than the transmitter power the power received; obviously, it is a gain. So, I am writing the symbol plus here, and symbol is P t. Next I am going to account for transmit antenna gain, this is G t, this is transmit antenna gain.

Now I am going to subtract the median link propagation, hence I am going to subtract median. So, this is the loss I am going to subtract, this is L 50, then I am also going to subtract the margin, remember if you want to improve the reliability. We said we need an additional margin, so I need to account for the margin also, I am going to subtract in d B. Then at a receive antenna I have a gain, because of the receive antenna. So, that I am going to write as plus, because it is a gain this is the mobile receive antenna gain. The receive antenna gain is G r, then from this I am going to subtract the cabling losses, because the losses. Cabling losses L r c, further to this I am going to subtract; receiver noise power and also interference.

Hence, I am going to subtract; remember there is a noise power at the receiver other thing to do is thermal, that is also interference from other users, remember we looked at systems like CDMA, where the other uses cause interference to the desired users even. In fact, in OFDM, where there is loss of frequency or there frequency offset. Hence, we said we are looking for signal to not noise power but, signal to interference plus noise power ratio.

Hence this is characterization of noise and interference power, which you were subtracting. This is N plus I and that I have equal to the required SNR, which is nothing but, SNR required. So, what we have here is that the path loss thus the transmitted again minus the link loss minus the margin, plus receive antenna gain minus cabling losses, minus noise and interference equals to the required SNR. This is nothing but this is essentially nothing but, simplistic representation of the link budget. Which is essentially the losses and gains of the different components in this transceiver chain.

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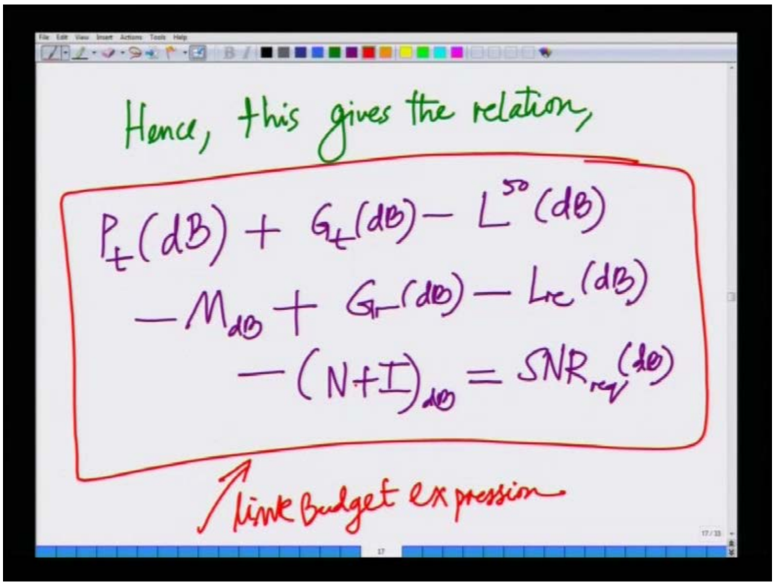

And we can also express this, hence essentially writing this down. Hence this gives…Hence this gives the relation transmit power and d B plus gain of transmit antenna d B minus 50th percentile path loss minus margin in d B plus gain of receive antenna in d B minus cabling losses in d B minus noise plus interference in d B equals SNR required, of course in d B. So, this is the first link budget expression; this is the link SNR required is the nothing but, transmit power plus transmit gain path loss minus margin plus gain of receive antenna minus cabling losses minus noise plus interference power.

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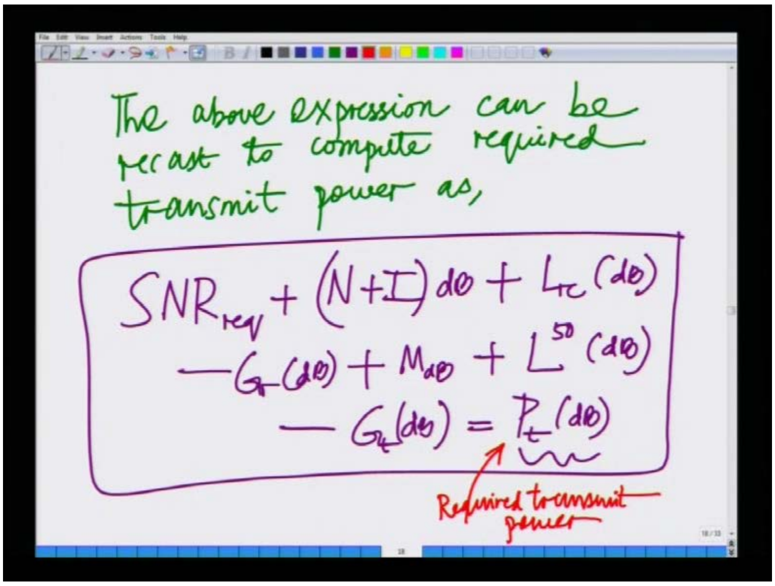

Flipping this on it is said, that is writing this in another way, this also can be recast to compute the required transmit power now as, the above expression can be recast to compute required transmit power, it can be re cast to compute required transmit power, as follows; that is SNR required is now SNR required that is I move all these terms on to the right side expect except P t, which is the for hence, the SNR required plus n plus I d B plus L r c d B minus G r d B plus M d B minus plus L 50 d B minus G t d B equals the required transmit power P t in d B. This is another way to compute the required transmit power, this is nothing but, the required transmit power, in terms of the different losses, and gains in the system.

Hence this is the required transmit power, in terms of the how to budget for this, in terms of the required in terms of the different components, in from the transmitter to the receiver.

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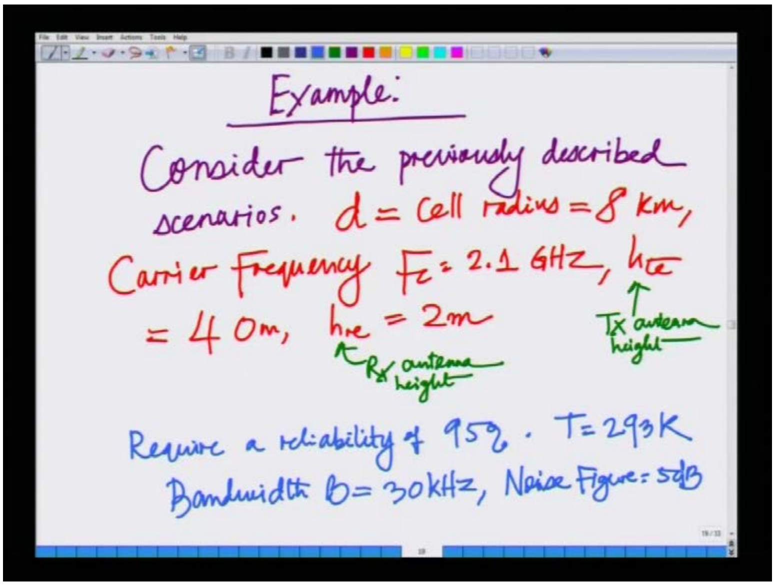

Let us do an example to understand the better, let us do an example to do everything together. In fact, there is scenario that we have discussed described previously, consider the previously described scenarios, if you look at the previously described scenarios, we consider that is consider d, which is the distance equal to the cell radius equals 8 kilometers. We consider the carrier frequency; we consider the carrier frequency that is F c equals 2.1 giga hertz. We consider transmitter antenna heights equals 40 meters, and the receive antenna height equals 2 meters.

This is similar to what, we considered in the ukumura model F c is the carrier frequency, d is the distance, h t equals transmit antenna height h r e equals receive antenna heights, just write this again, this is the T X antenna height, and this is the R X antenna height. And, we require a reliability we require a reliability of 95 percent, the temperature is 293 Kelvin. This is what we seen in the noise competition example, and the bandwidth B equals 30 kilo hertz noise figure equals 5 d B, and here have also we have to add when we require the reliability of 95 percent, the variants of the log normal shadowing.

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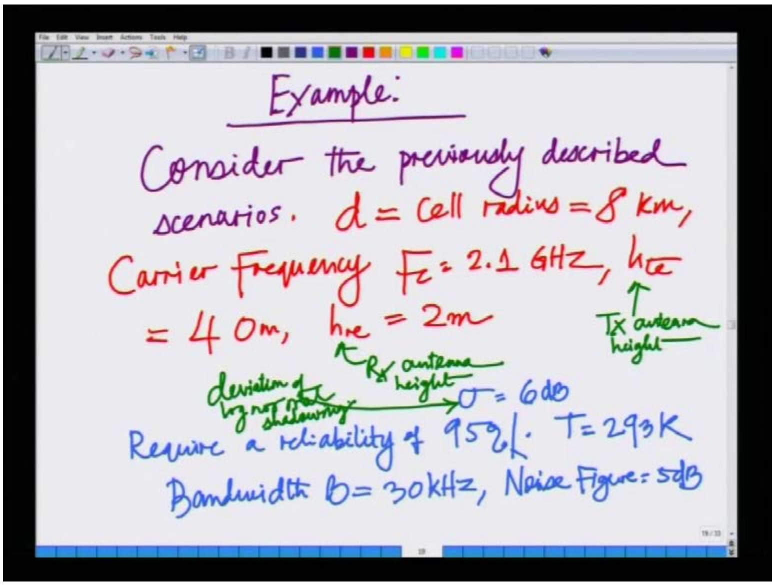

Similar to we said earlier, that is variant sigma equals 6 d B. Sigma is nothing but, the variants of log normal shadowing; this is nothing but, a deviation this is not the variants deviation, but this is deviation of the log normal… This is all that we considered previously in previous examples.

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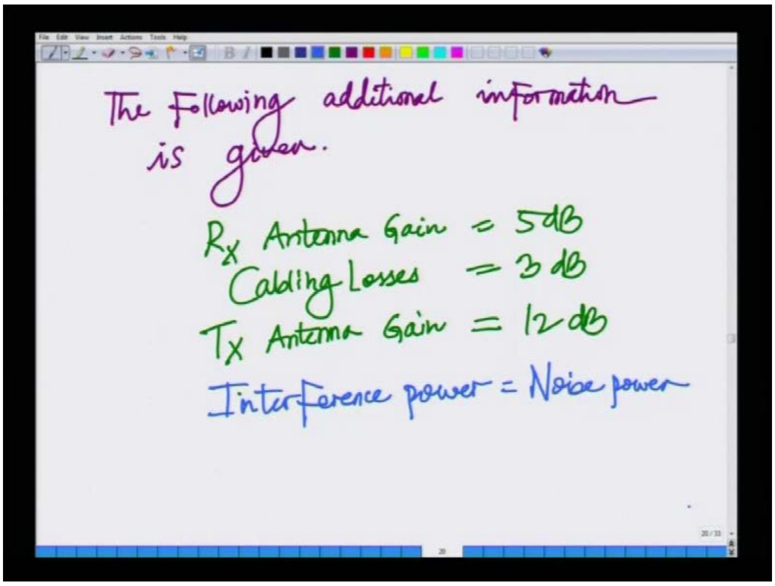

Now, we have some additional information also consider the following additional information. The following additional information is given, that is R X antenna gain is 5 d B the cabling losses equals 3 d B. The T X antenna gain equals 12 d B, and the noise power it is given that the interference power is equal to the noise power. So, the interference power I the interference power I equal to the noise power, and what we have to compute is it is asked to compute employing the information above we to compute the transmitter required.

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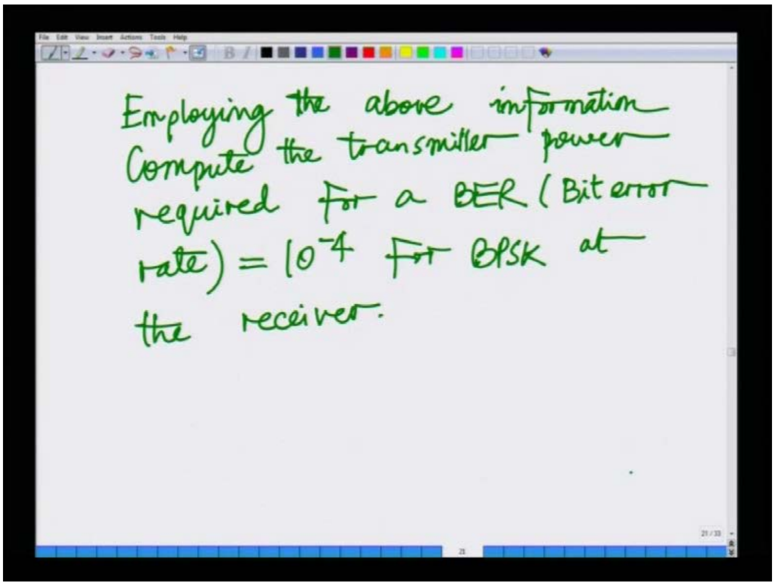

Employing the other information compute compute the transmitter power compute the transmitter power required for a bit error rate for a BER, which essentially stands for bit error rate equals 10 power minus 4 whole BPSK at the… So, what we have asked is obvious that we have this is the kind of long problem statement. What we have begin here is we have started with about a list of items, and what we are now being asked is that essentially in this wireless cellular system; characterize or compute the transmit power required at the transmitter of the base station. Such that I have enough power or signal to noise power ratio.

So, that I can decode BPSK transmition at the rate of 10 power minus 4, so that is the requirement of the problem, which is to compute the transmit power, using this different components of the link budget, and naturally we have to use the link budget analysis.

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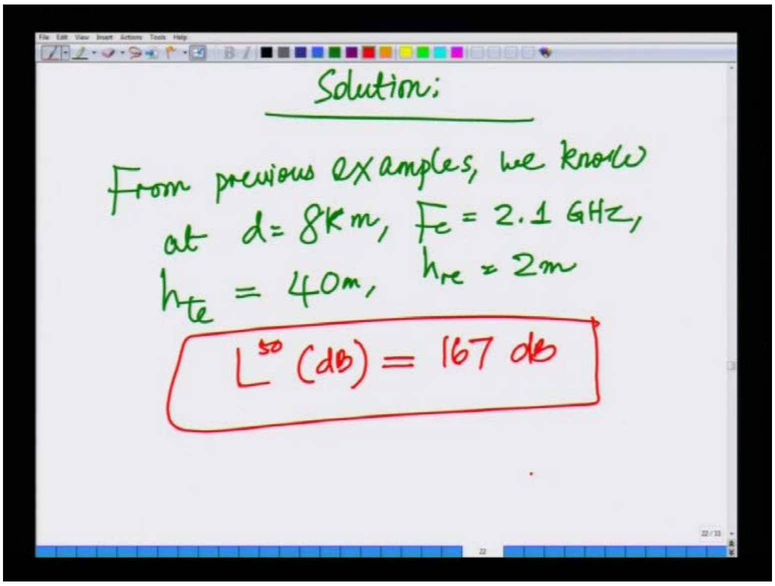

Let us start with what we already have, we already know from the previous examples; that at… So, let us start the solution from previous example, we know at d equals 8 kilometers and F c equals 2.1 giga hertz and h t e equals 40 meters and h r e equals 2 meters. We know it and we computed it both h ukumura and the hata models, we know that we know that it is L 50 or the 50th percentile of d B is 167 d B; this is the first peace of information and we know, that at the distance 8 kilometers 2.1 giga hertz and this transmitters and the receiver heights path loss is nothing but 167 d B. Then we also know that for 95 percent of reliability, the margin required is 10 d B that is what approximately 10 d B that is what we computed for…

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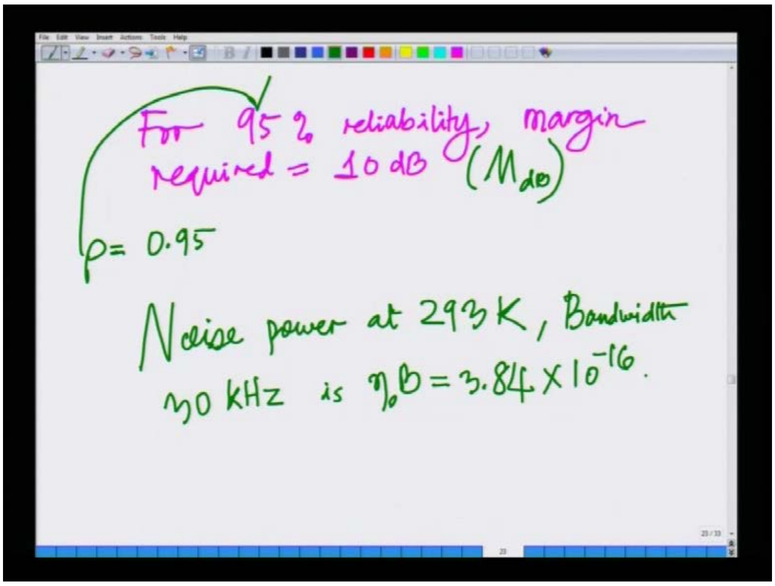

The margin required is 10 d B for 95 percent reliability that is we said this is nothing but, correspondence to row equals 0.95; this is computed at 95 percent reliability that is row equals 0.95, the required margin which is nothing but, M d B for 10 d B. Further we computed that the noise power at 293 Kelvin, and bandwidth of 30 kilo hertz is eta naught B, which is to equals 3.84 into 10 power minus 16.

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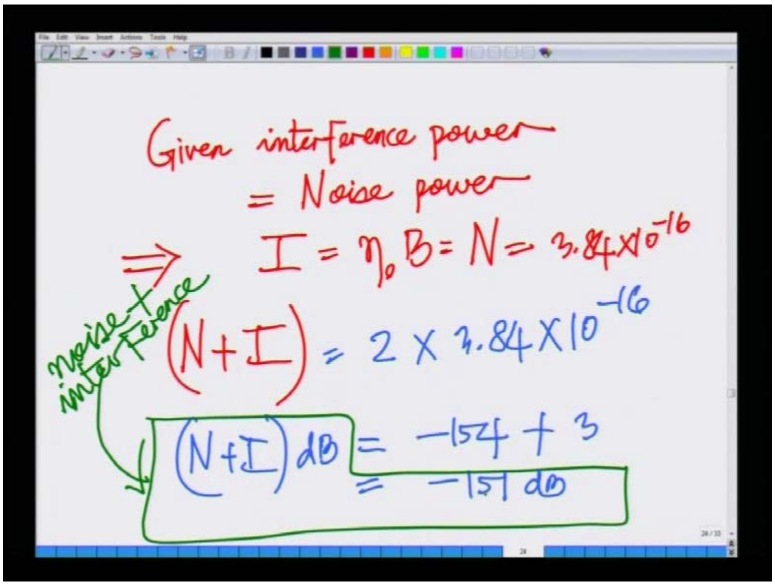

And we are also given that interference power which is equal to noise power. Given that the interference power, which is equal to noise power, implies I is also equal to eta naught B equals N equals 3.84 4 into 10 power minus 16. It is given in the that interference power is equal to noise power. The noise power we already computed in the parameter is 293 Kelvin, and noise figure 5 d B is 3.84 into 10 power minus 16, and interference power is also equal to noise power, which is equal to 3.84 into 10 power minus 16.

Which now means N plus I is nothing but, twice 3.84 into 10 power minus 16 computing this value into d B. This is nothing but, minus 154 plus two factor two corresponding to 3 d B, which is essentially minus 151 d B.

Hence, the noise plus interference power in d B, this is nothing but, noise plus… This is nothing but, the noise plus interference power required noise plus interference power in d B which is nothing but, minus 151 d B. Now let us compute another aspect which is the required SNR, we are told that SNR required is enough to support BPSK decoding at 10 to the power minus 4.

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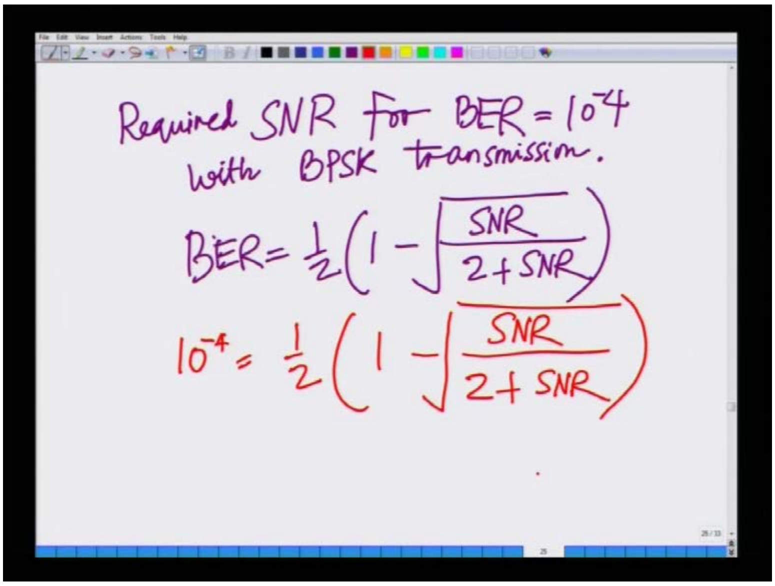

Hence, are the required SNR for BER equals 10 to the power minus 4 with BPSK. Remember in the early part of the class, we derived that the expression for bit error rate for BPSK, and that bit error rate is nothing but, 1/2 into 1 minus SNR by 2 plus SNR, now we require bit error rate of SNR, now we can write 10 to the power minus 4 1/2 into 1 minus SNR by 2 plus SNR.

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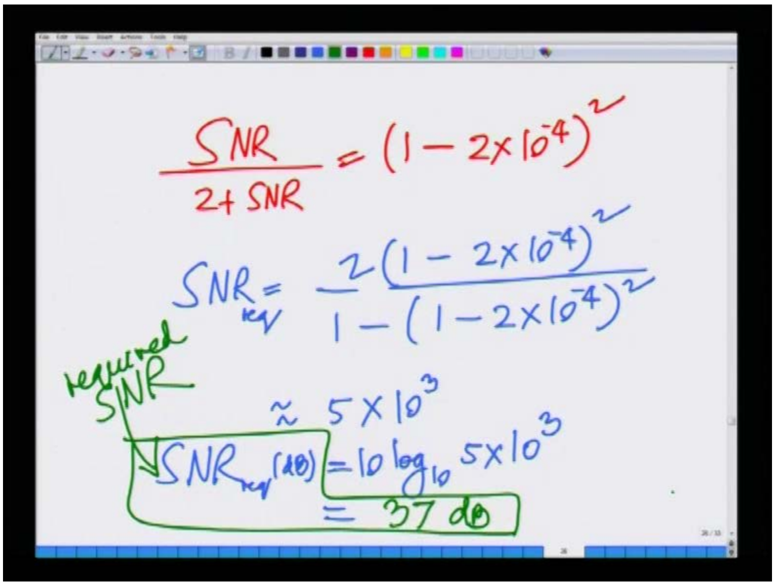

Now, re arranging this terms, we can write SNR by 2 plus SNR equals 1 minus 2 into 10 to the power minus 4 whole square, hence I can write I can also write SNR, the final expression of SNR is twice 1 minus 2 into 10 to the power minus 4 whole square divided by 1 minus 1 minus into 1 minus 2 into 10 to the power minus 4 whole square, which is essentially approximately equals 5 into 10 the power 3.

Hence SNR required this is nothing but, SNR required is essentially SNR required for 10 to the power minus 4 bit error rate in BPSK. Hence SNR required in d B is 10 log 10 5 into 10 power 3, this Is nothing but, 37 d B, hence the SNR required in d B is nothing but… This is nothing but, the required this is nothing but, the required SNR in d B.

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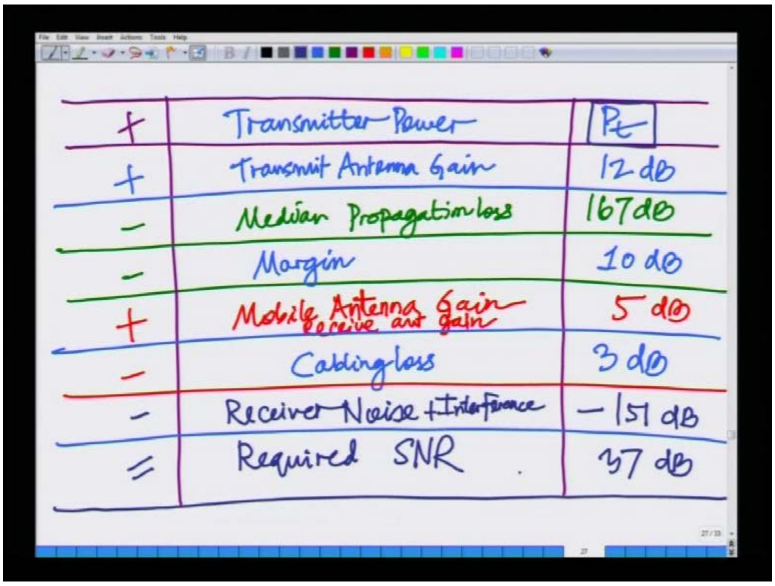

Now, we put all these things together in the link budget. Hence we can formulate the link budget as follows; the I going to again draw the table. First we have the transmit power P t, remember this transmit power is un known… This is what we have to compute transmitter power P t, this is plus transmit antenna gain g t, remember this is given as 12 d B, if you look at the problem information this transmit antenna power gain is given as 12 d B plus minus median propagation loss is 167 d B minus the margin required path loss is 167 d B and minus margin margin we said is 10 d B, and we have mobile antenna gain or the receive antenna gain, which is essentially the receive antenna gain which is essentially 5 d B, and then we have cabling losses minus cabling loss which is 3 d B.

Further we have receiver noise… Further we have receiver noise plus interference, which is given as minus 151 d B, and that should give us the required SNR, which is nothing but, required BER decoding of BPSK with bit error rate 10 power minus 4, and that we said is 37 d B. Hence we have written all the components in our link budget. What is remaining is to compute this transmit power P t due to lack of time I am going to stop it here, and the next time when we return, we are going to complete this example, and going to the next topic.

Thank you very much.