Millimeter Wave Technology
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Module 7
Lecture No 34
Noise and Link Budget (Contd)

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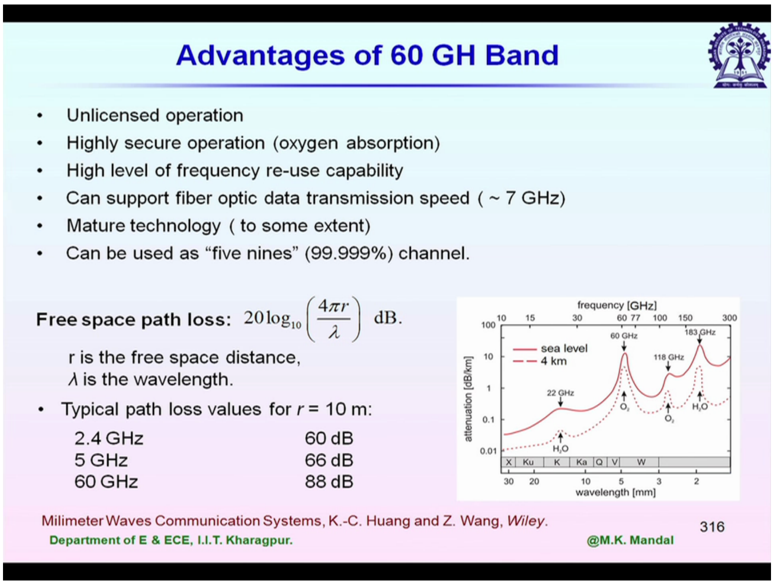

So next we are going to discuss about 60 gigahertz channel and presence of noise. So from the previous slide what we have seen that because of this higher frequency we have very high attenuation due to path loss and it is 28 dB higher compared to 2.4 gigahertz, and if I compare this value because of attenuation due to atmosphere that is only 10 to 12 dB per kilometre, so much higher compared to that value.

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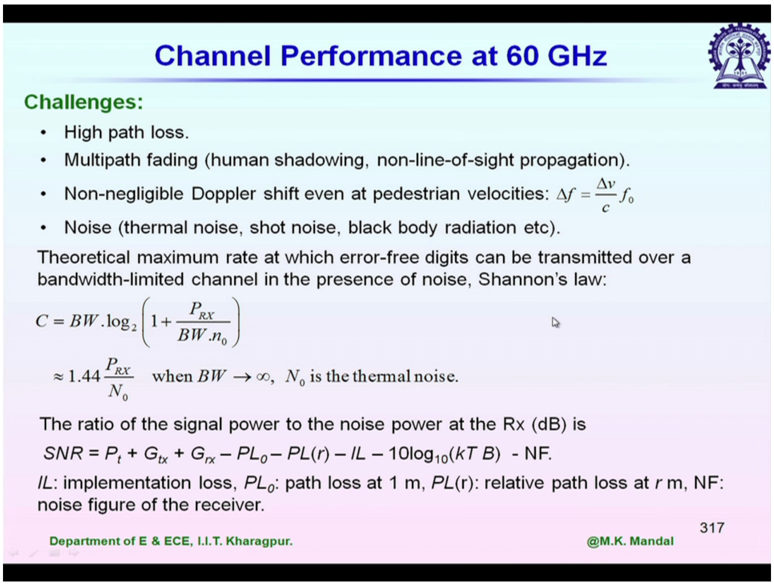

So channel performance at 60 gigahertz, the first problem we will be facing is high path loss value, then multipath fading effect, we have human shadowing effect. Human shadowing effect it can be as high as 20 dB, so if let us say there is a link and any human is now present between the transmit and receive antennas, then the received power it can be it can be it can degrade by even as high as 20 dB, so that we have to keep in mind, then non-line of sight propagation that is due to multipath, non-negligible Doppler shift even at pedestrian velocities because we know Delta f change in velocity Doppler shift change in frequency that is Delta V by c into f 0 and also we have effect of noise. So this noise it becomes an important issue, we will discuss in details about this noise, there are many sources of noise, thermal noise, it can be shot noise, Flicker noise, blackbody radiation.

So what is blackbody radiation? Because of the temperature of different objects they are constantly radiating, we can model them by blackbody radiation curve Plank's law. And antennas, receiving antenna it will collect this radiation as well and it is a undesired signal and noise for the system. Then theoretical maximum rate at which error free digits can be transmitted over a bandwidth limited channel in the presence of noise it can be given by Shannon's law, it is channel capacity C it is equal to bandwidth of the channel multiplied by Log you note down here base is 2, log of 1 + received power P rx divided by bandwidth multiplied by n 0, n 0 this is noise per hertz, so total receive noise is bandwidth multiplied by the n 0 value small n 0. Approximately it is equal to 1.44 divided by receive power by total receive noise power, here we are considering only the effect of thermal noise, so N 0 it represents thermal noise.

We can also call them this P rx by capital N 0 this term SNR of the receiver, signal to noise ratio at the receiver. So this formulation when we assume that bandwidth is sufficiently high fence to infinity. So SNR, it becomes one very important quantity, channel capacity it depends on this value and already we learned how to calculate SNR in presence of noise, so ratio of the signal power to the noise power at the receiver in dB is SNR this is P t G of transmitter, G of receiver - now the path loss we are dividing it into 2 components; PL 0 and PL r, why? PL 0 it represents the path loss at 1 meter and then after that we have a different coefficient L for path loss calculation we call it relative path loss at armature. So for the first 1 meter we will consider n equal to 2 in that path loss formulation that means 20 log 10 4 Pie r by Lambda.

And for the next part after 1 meter we have to experimentally determine what is the value of L usually varies between 3 and 5, which we discussed earlier. So now why first for first 1 meter we are using Friis equation directly? If we have any transmitter, it can be placed on top of any pole outside or inside even any room, let us say it is placed at any one corner of the room, so at least for first 1 meter we can consider it is arm obstructed and we can use the Friis. So after that we will be considering the effect of all these multipath effect, fading effect, human shadowing effect and we will consider a different value of L, so that is why we are dividing this path loss components into 2 parts. First part due to the first 1 meter from the antenna and second part after 1 meter.

Next is the IL, we call it the implementation loss so it represents all the losses in cables, antennas, et cetera. Then we can calculate the noise contribution, we are calculating SNR so we are subtracting now the noise component, now there are different sources of noise for any given device. If we have antenna, antenna it has metallic part dielectric part, it will add some noise, if we have cable again inside cable it will add some noise, if we have amplifier, it will also add some noise so the noise contribution and how to calculate the overall noise we will discuss after this in detail. So sometimes some devices it comes with a noise factor, so noise factor is nothing but it is a ratio of SNR at the input terminal to SNR at the output terminal of the device, if the noise factor is given we can directly put the value here.

So now the thermal noise it depends on the effective noise temperature of the system and the bandwidth. If we increase the bandwidth of the system, we will pick up more thermal noise so we have to then subtract these 2 components; one due to thermal noise and another one, which is coming from the active devices which is given by the noise figure of the device. So then in the expression we have - 10 Log 10 KT B, we are using decibel scale - noise figure, we are assuming noise figure is given in decibels. Once we have this information, we can calculate then SNR signal to noise power at the receiver and we can calculate then what is the channel capacity of that particular given channel.

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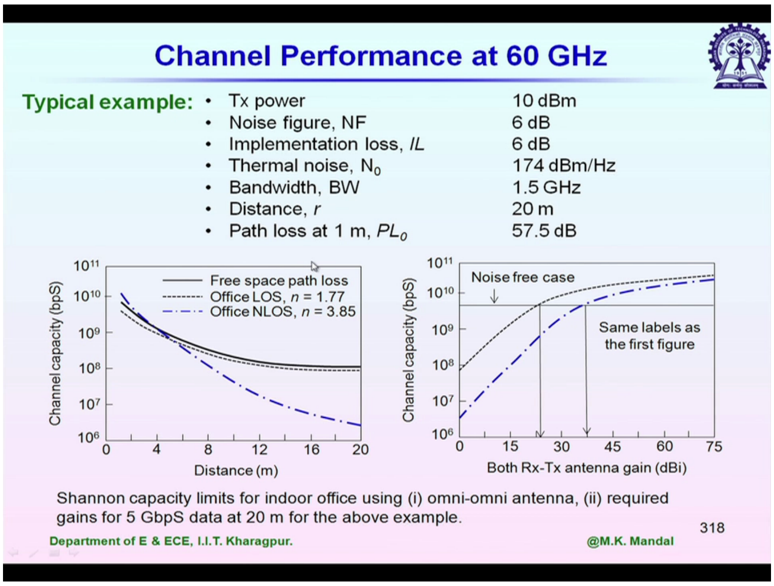

Let us take many medical example, let us say transmit power is given as 10 dBm, so 10 dBm in milliwatts it is 10 milliwatts. Noise figure, this overall noise figure is already calculated and given 6 dB, implementation loss IL is given 6 dB, thermal noise you can calculate K into T, it comes 174 dBm per hertz. Bandwidth of the system 1.5 gigahertz and distance between the transmit and receive antennas 20 meter and the path loss at 1 meter, which is PL 0 if I put the values at 60 gigahertz and consider N equal to 2 in that expression of path loss it comes 57.5 dB. Now here is the plot of channel capacity in bits per second versus distance, so for the specifications we will consider are equal to variable and we are changing it from let us say 1 meter to 20 meter and we are considering different scenarios for indoor models.

Inside office for line of sight communication n that path loss index in Friis equation it was n = 2. Here inside office we are considering n = 1.77 and for Non-line of sight communication it can be via reflection, n = 3.85 we have higher loss so these are some experimental values, we are considering them indoor communication inside let us say office building. Now let us see how the channel capacity to varies with distance for this given specification. So this black line solid line, it represents free loss according to Friis equation. And we see if I increase distance, then nice power it does not change but receives power it changes, it decreases. So accordingly channel capacity, it decreases so at 20 meters a day somewhere in between 10 to the power 8 to 10 to the power 9 bits per second even though bandwidth is given 1.5 gigahertz.

And you see for line of sight communication indoor communication n = 1.77 more or less it following the curve for n = 2, but for non-line of sight communication when n = 3.85, if I follow this blue line it decreases to 10 to the power 6 to 7 somewhat in between this value at 20 meter, so you see the effect of noise and distance. If we have higher n, then SNR decreases as a result channel capacity also decreases. Now we are considering another scenario, here we are plotting channel capacity article channel capacity versus antenna gain, so what is the minimum antenna gain required to maintain a given channel capacity of 5 GBPS. So 5 GBPS is my target, so for that we need to maintain a typical SNR value and we are considering let us say the separation between transmit and receive antenna is 20 meters.

So then SNR if I consider the specifications given above, only thing is that will change receive and transmit antenna gain and we are assuming receive and transmit antenna they have the similar gain, the same gain value. So if we need to maintain now this 5 Gbps data rate at 20 meter, we have to maintain receive or transmitter gain value the typical gain value given by these curves. For example, let us say n = 1.77 this black daughter line, so for 5GBPS channel capacity antenna gain required at least a somewhat this is 15 30, so 23 dBi both for transmit and receive antenna. Now if n = 3.85 for non-line of sight communication, minimum antenna gain it increases to 37.5 dBi if we need to maintain that 5 GBPS data rate at 20 meter. So here we are considering that we do not have any control over transmit power and other things, only thing we can change the gain of the antennas. And this plot shows then what should be the minimum gain of the antennas to maintain this 5 GBPS data rate at 20 meter separation.

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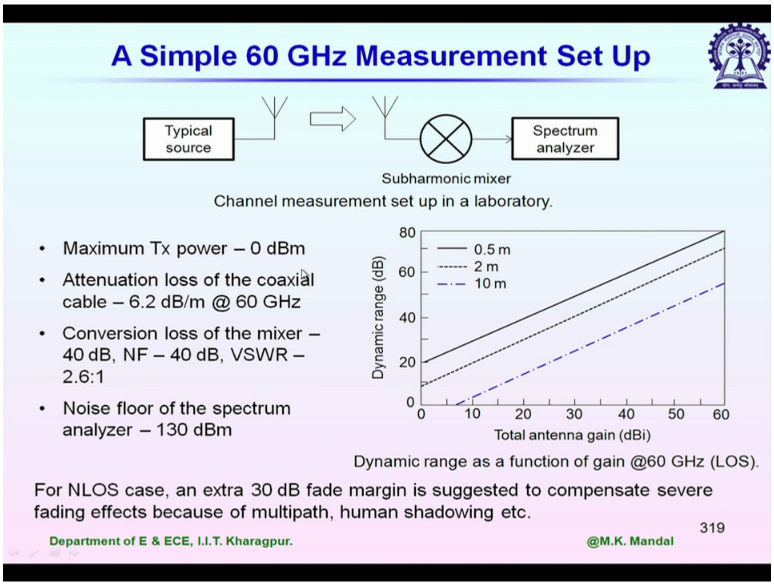

A typical 60 gigahertz measurement setup it can be anything, for this example we are considering let us say we are going to characterise one antenna, which is separated from the transmitting antenna at different distances. We are considering transmitted power is 0 dBm that means 1milliwatts. Attenuation loss of the coalition cable 6.2 dB per meter at 60 gigahertz, conversion loss of the mixer so you see in a typical system at millimetre wave frequencies we know that at millimetre wave frequencies the component cost is very high, so for any given system then what we do, we try as soon as possible to down convert the frequency. So just after antenna it may be a band pass filter or low noise amplifier then we use a mixer to down convert the frequency. If you look at any practical instrument for example, let us say spectrum analyser; inside the first stage it might use one mixer to down convert the frequency.

So once it is down converted to lower frequency, then we can use cheaper low-frequency component. So in this example also we are using a sub harmonic mixer for down conversion and mixer it comes with some conversion loss so if you feed some power to mixer, which is millimetre wave power, when it will down convert to microwave frequency or RF frequency then the power available for that RF or microwave signal it will be much less compared to that millimetre waves frequency. So for this one the loss or because of this change in frequency, which you call the conversion loss of the mixer it is 40 dB, so RF power available it is 40 dB down compared to the millimetre wave power at the left-hand side.

So this is a typical value for a passive sub harmonic mixer, we have some different categories of mixer, for them sometimes it can be improved to even let us say 0 dB, noise figure since conversion loss is 40 dB, noise figure is also 40 dB and VSWR of the mixer is given by 2.6 is to 1, and noise floor of this spectrum analyser is - 130 dBm, so this spectrum analyser can sense power till - 130 dBm at the rate of 60 gigahertz. Then what is the maximum and minimum power we can measure by using this system? The minimum power it depends on SNR, again we have to calculate SNR for the system and since the device under test or antenna under test it is connected to the sub harmonic mixer, so we cannot change this one, so only control we have only transmit antenna gain or maybe we have we can increase the transmit power, so we will see then for different total antenna gain what is the minimum power we can sense by using this spectrum analyser at different distances.

And what limits the maximum power? Maximum power it is limited by nonlinearity of the device, when we design any system it can be microwave system or millimetre wave system, even a low-frequency amplifier we consider it as a linear device so that is why a low-frequency amplifier sometimes we call small signal equivalent circuit or small signal amplifier. Now, if I increase the power input power in that case it can move to its non-linear region and then we have to model it in different ways and it will be associated with other high-frequency components. So maximum power would be then limited by the nonlinearity of the devices are being used in the system. Here we are considering the minimum power and maximum power difference, so it is calculate it for this data set, so dynamic range for this measurement setup then it varies with antenna gain and distance because of the different SNR value.

So at 10 meter you see when the antenna gain is less than let us say 6 or 7 dBi, it cannot sense anything you do not have any dynamic range. To sense anything, it starts from approximately 7 dBi and now if I keep on increasing the antenna gain so in that case this dynamic range will increase, so maximum to minimum power that can be dynamic range it is the difference between the maximum and minimum power that can be sensed by this system. Now obviously we decrease the distance let us say to 0.5 meter in that case we have some dynamic range even 0 dBi gain and if I increase the antenna gain, then dynamic range increases.

So when we are going for any measurement or any antenna or any other things that time also we have to keep in mind what about the, what is the SNR and because the dynamic range it also depends on SNR of the receiver. So here you see for non-line of sight communication and extra 30 dB fade margin is suggested to compensate severe fading effects because of multipath, human shadowing, et cetera, for this plot reconsider line of sight communication. Next link budget, typical we are considering for indoor model.

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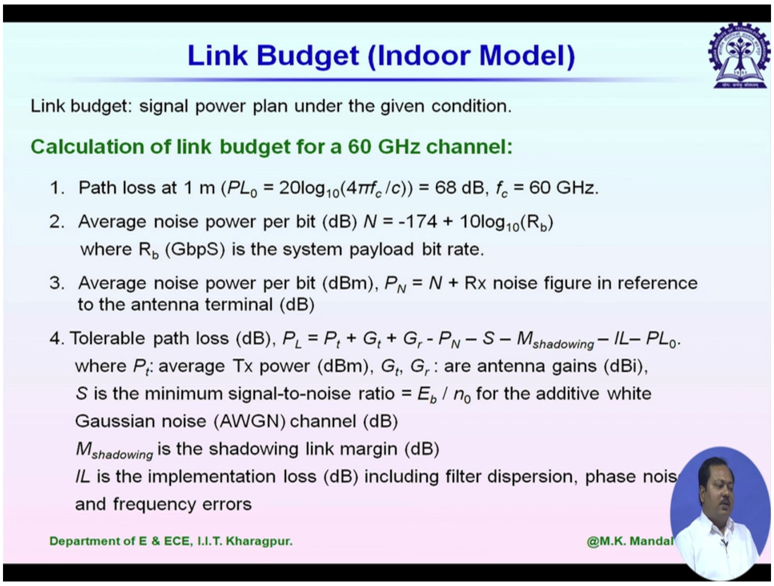

So link budget it is basically signal power plan under the given condition. You do not have any control over noise figure and the noise contribution then depending on the receiver to transmitter maximum separation what should be the minimum antenna gain value, what should be the minimum transmit power so all these are calculated using this link budget. So the calculation let us say we are considering at 60 gigahertz, it starts with the path loss calculation. Now for the first 1 meter we will consider we will consider the path loss it is 20 log 10 4 Pie f c by C, so if I put f c equal to 60 gigahertz, it comes 68 dB. Average nice power per bit N, this is equal to - 174 10 log 10 of R b. So this 174 how it comes, you see thermal noise at the input it depends on the noise temperature T and the noise bandwidth B, kTB.

Now if we put the value of k and T and calculate thermal noise power per hertz, then you put k equal to Boltzmann's constant that is 1.381 into 10 to the power - 23 watt per hertz per Kelvin. And if nothing is specified, we will consider T equal to 290 Kelvin, it is called the room temperature, support the values here then it will come 4.005 into 10 to the power - 21 watt per hertz and if I convert it to decibel scale dBm, - 174 dBm per hertz. So B bar we are calling normalised bandwidth of 1 hertz. Now if we have a rate R b, then we need to add the contribution because of this bandwidth and it is 10 Log 10 of R b, R b this is the system payload bit rate. So then average noise power per bit in dBm P N, this is equal to N + R x, noise figure in reference to the antenna terminal.

Tolerable path loss P L, the previous formula in addition to that we are considering M shadowing that shadowing effect, so for human body it can be 15 to 20 dB so depending on scenario we have to put a suitable value for M shadowing and here S is the minimum signal-to-noise ratio for E b by small n 0 for the additive white Gaussian noise channel. And I L, this is the implementation lost in dB including filter dispersion, phase noise, if there is any frequency error so everything is taken into account in IL, then we can calculate total loss from here.

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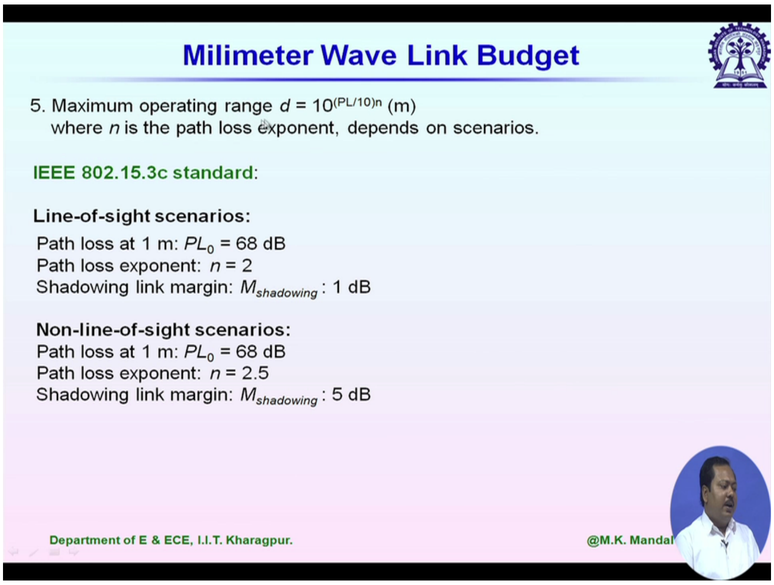

Then maximum operating range d, it can be given by 10 to the power PL divided by 10 into n, where n is the path loss exponent. So for ideal case in free space n = 2, but for indoor model n depends and it varies from room to room, we have to use some experimentally fit value for small n. Here are some examples suggested for IEEE 802.15.3c standards. For line of sight scenario consider 68dB, path loss exponent n = 2 and M shadowing just 1 dB, this is called shadowing link margin. But for non-line of sight scenario path loss at 1 meter same value 68 dB, consider path loss exponent small n = 2.5 and shadowing link margin = 5 dB, so these are some suggested value for this IEEE standard. Okay, so we will take a break then we will calculate link budget for a given system, thank you.