Millimeter Wave Technology
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Module 7
Lecture No 32
Noise and Link Budget (Contd)

So next we will see the characteristics of millimetre wave when it propagates through any channel. The main advantage of millimetre wave is high frequency, so we can increase the channel capacity to a few gigahertzes or even we can target 10Gbps channel speed. But it is associated with some other problems like high atmospheric loss, high loss due to rain fade, then multipath effect, so let us discuss these points first then we will be modelling some channel and calculate Link budget for a given millimetre wave line of sight system. So millimetre wave first of all have high atmospheric attenuation.

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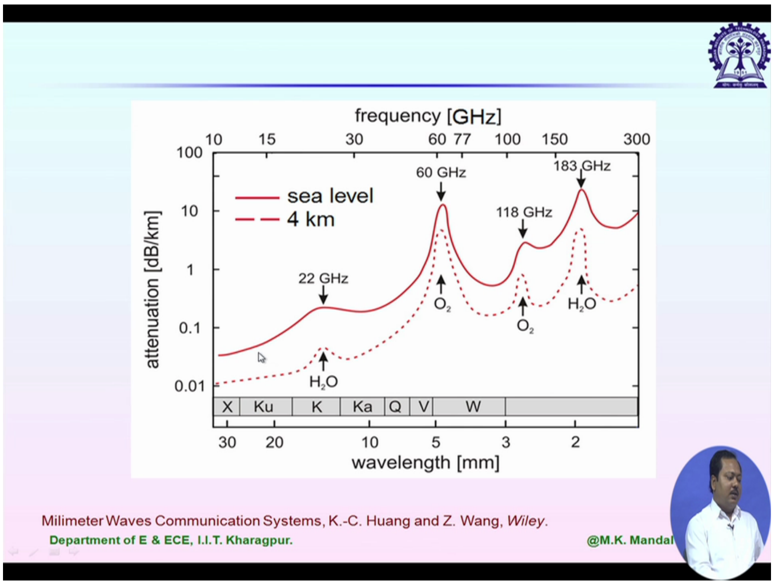

So this curve we have seen in first class, this is the plot of attenuation in dB per kilometre versus frequency, so the frequency scale is shown on top starts from 10 gigahertz to 300 gigahertz, covers some part of microwave frequencies as well as millimetre wave frequencies, the corresponding free space wavelength is shown here. So now if I follow this curve we have 2 plots, one at sea level for attenuation and the second one, the attenuation has been measured at a height of 4 kilometres from sea level. So at sea level attenuation is higher and we see that if frequency increases, attenuation also increases. And not only that, we have some attenuation peak, these are due to resonant frequencies of different types of gases. For example, at 22 gigahertz we have a small increment, it is due to the resonant of water molecule, water vapour and at 60 gigahertz we have a peak, it is due to the resonant of oxygen molecule.

Similarly, we have another small one at 118 gigahertz and another high peak at 183 gigahertz again this is due to water molecule water vapour, so we cannot use all the bands for millimetre wave propagation. For example, if I want to use this 60 gigahertz band then we will face very high attenuation due to oxygen resonant band. We have to use then these windows available in between 2 peaks for millimetre wave attenuation so this will give minimum loss. Another interesting thing, even if I look at these windows and compare the attenuation with that at microwave frequencies, we see that at 10 or 15 gigahertz whatever attenuation we have it is less than 0.1dB per kilometre at sea level. But this attenuation it increases to at least 1dB let us say above 118 gigahertz.

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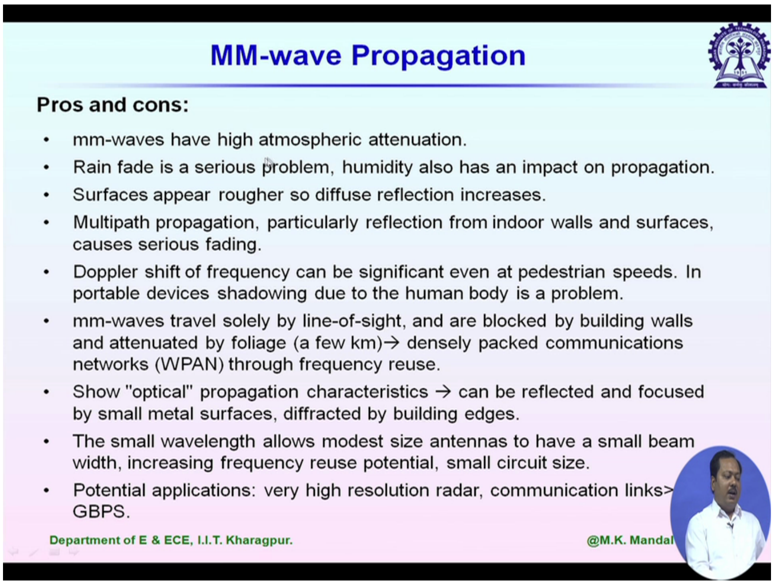

So at millimetre wave frequencies even if we even if we do not use this attenuation band, in between attenuation band also attenuation will be higher. But if we go high in atmosphere, in that case we can decrease attenuation to some extent for satellite communication typically. So millimetre wave has high atmospheric attenuation compared to microwave signal. Then rain fade it is a serious problem, so whenever it is raining in medium in that case there will be scattering of microwave or millimetre wave signals by raindrops and the scattering it increases with the droplet size, so higher rain rate it is associated with higher scattering effect or in other words it will provide high attenuation. Now when the droplet size is comparable to wavelength of the propagating signal, we have the phase maximum scattering.

So it high rain rate, typically at higher millimetre wave frequencies we have very high attenuation. But one good thing is that if I compare these attenuation values with the attenuation whatever we have at infrared frequencies or at optical frequencies, millimetre wave attenuation is much smaller compared to them. So when it is raining heavily, in that case any infrared link or optical link it can fail completely, but millimetre wave link in that case also it can operate, sometimes we called that is why a millimetre wave link all-weather link or all-weather system. So next, surface appear rougher so diffuse reflection increases. So again surface, any reflecting surfaces any practical surface it is associated with some sort of roughness.

Now the RMS value of roughness if it is much smaller compared to the free space wavelength of propagating signal, in that case we can consider it as a smooth surface and we will be having smooth reflection also. But at millimetre wave frequencies, where the wavelength is typically less than 1 centimetre sometimes if I go to high millimetre wave frequencies it is almost 1 millimetre, so surface it will appear rougher and we have diffused reflection from wall and from the furniture and from any buildings, foliage, trees also. Multipath propagation, particularly reflection from Indoor walls and surfaces causes serious fading problem. So fading problem you might have seen even for an FM radio, you might have experienced.

For example, let us say at this position you are getting signal for your FM radio, but if you move 1 or 2 meter away you are not getting any signal. Similar problem will happen for the millimetre wave but in this case since the wavelength is much smaller just if you move your instrument a few millimetre, you may not get any signal so this is a serious problem. Doppler shift another problem, even as pedestrian shift because Doppler shift it is proportional to velocity as well as it is proportional to carrier frequency and at millimetre wave frequency carrier frequency is very high. So even at pedestrian frequency the value whatever we get, it may not be negligible small so we have to consider Doppler shift also.

Millimetre waves travel solely by line of sight and are blocked by building walls and are attenuation rate by foliage, so if you compare microwave signals let us say at 2.4 gigahertz where wavelength is quite high, so if any person he or she stands in front of any transmitter then we have diffraction effect. So you can say as if microwave signal bends around human body at lower frequency or the blockage effect or shadowing effect we can say due to human body is negligibly small at lower microwave frequencies. But if we go to higher frequencies, then just like optical rays we face shadowing effect due to human body. So if we place a transmitter behind me, so in front of me we do not have any millimetre wave signal, so it is a problem for indoor applications. And not only that, it will be also attenuated by foliage, we have tree leaves, tree branches, so all of them will attenuate or reflect millimetre wave signal.

So it becomes a problem then for line of sight millimetre wave communication, so maximum distance can be used to let us say just a few kilometres, if we do not go to free space. If we consider a scenario on earth, so it is a problem but it also has an advantage that we can go for picocell if we think for mobile communication. So fame frequency component we can repeat just after a few kilometres without any interference, so then densely packed communication network through frequency reuse we can develop. And it shows optical propagation characteristics, so that means it can be reflected and focused by small metal surfaces and diffracted by building edges. So small wavelength, it allows modest size antennas to have a small beam width, increasing frequency reuse potential and small circuit size.

Now antenna again, it is proportional to the physical area of the antenna in comparison to the wavelength lambda. So if we have smaller wavelength, but if we use same area to realise any antenna at millimetre wave frequencies, it will provide much higher gain compared to at microwave frequencies so we can easily design very high gain antenna. Not only that, already we learned some circuit components like let us say filter, coupler, where we use properties of transmission line, so typically length is given in terms of lambda G so for these components than the size at millimetre wave frequencies it becomes very small, so very compact components can be developed and as a whole millimetre wave system it will occupy small volume.

So typically potential applications, very high-resolution radar, communication links even more than 10Gbps, now people are talking about 5G wireless communications and 5G wireless communications nobody knows what will be the final frequency but obviously it would be at millimetre wave frequency due to these advantages of millimetre wave frequencies.

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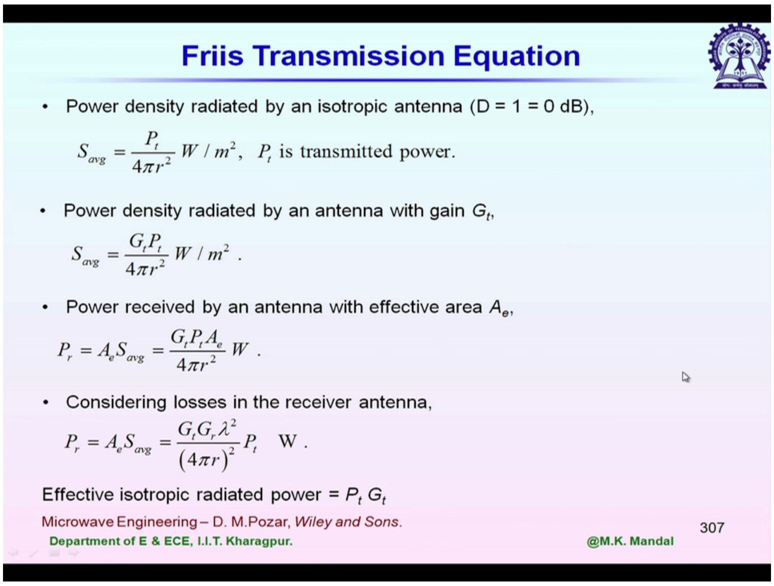

So next we will see the Friis transmission equation, let us consider we have one isotropic antenna, which is radiating up our P t in all the direction so that means its directivity is 1 or in decibel scale it is 0 dB. If I consider a spherical surface and let us say that isotropic antenna is placed at the centre of that sphere, then average power density on the spherical surface it can be given as P t divided by the total area of this sphere, so P t by 4 Pie r square watt per meter square, where P t this is the transmitted power. Now, power density radiated by antenna with gain G t, so in this previous example we consider isotropic antenna, now if the antenna it has some gain, in that case it will direct the beam in it will direct the energy in a given direction, higher is the gain then it will direct more in that direction, so obviously we will be having higher intensity in that particular direction.

So then S average in that case considering antenna again G t, this is equal to G t into P t by 4 Pie r square watt per meter square. Now let us consider, we have a receive antenna of effective area A e and it is placed on that spherical surface. So since its effective area is A e, so we can receive power P r, A e into S average, then in expression it is G t P t A e by 4 Pie r square into W. Now, receiver antenna it is associated with some loss obviously so that lost term it is included in the antenna parameter gain, so better to use antenna parameter gain of the receiver, let us say G r, then we have a formula that relates the gain of the antenna with its effective area A e and the wavelength, so we use that formula here then P r, it becomes A e into S average in terms of then gain of the receiving antenna, it is G t G r into lambda square by 4 Pie r whole square into P t in watt.

The term P t into G t, we call it Effective isotropic radiated power or EIRP, so this receiving antenna we assume that this is placed in the direction in which the transmitting antenna is sending its power in the direction of the main beam of the transmitting antenna. So we can simply consider that as if the transmitting antenna it is transmitting the effective power of P t into G t in every direction like the isotropic antenna so that is how the concept comes effective isotropic radiated power P t into G t.

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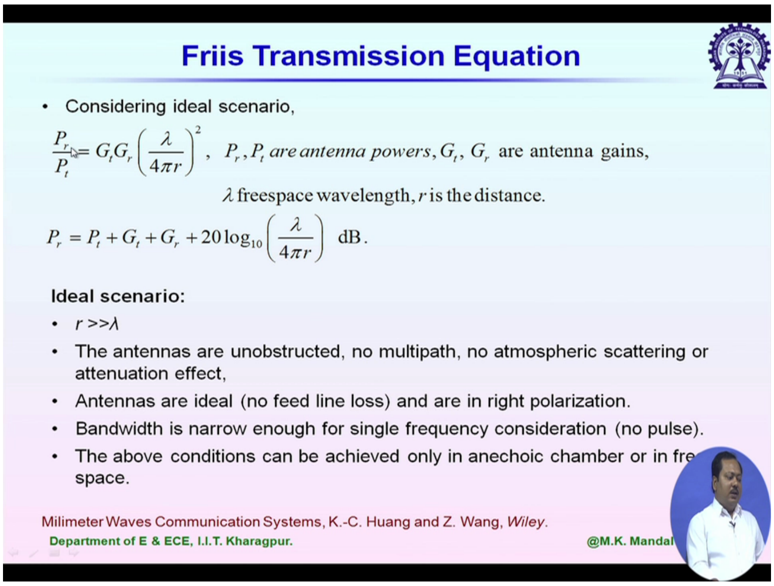

Then we can calculate the ratio of P r by P t from the previous expression, this is G t into G r by lambda 4 pie whole square, so this is obviously an ideal scenario where P r this is the received power, P t this is the transmitted power and G t G r are the antenna gains of the transmitting antenna and the receiving antenna and lambda this is the free space wavelength, r is the separation between the transmit and receive antenna. Now you see why we call it ideal scenario, in this expression we assume many points which may not be valid in practical scenario. For example, we are considering a single frequency component and representing it by free space wavelength lambda, so this is true only for a continuous wave but if we use any communication channel, it might have some bandwidth. So in most of the problems what we do then, we consider the mid-band frequency and calculate the corresponding lambda 0 at mid-band frequency.

Similarly, antenna has some polarisation, consider a dipole antenna so any electric field parallel to the arm of dipole antenna it can receive, but if any electric field which is perpendicular to arm of the dipole antenna it cannot receive. So here we are considering an ideal scenario where whatever power coming through receiving antenna, it is receiving all the power of there is no polarisation mismatch. Similarly, we are let us say the transmitting antenna is connected to a microwave source, then from microwave source whatever power delivered to antenna, the 100% power is not accepted by antenna, antenna has some input reflection coefficient we represent it by S 11. So depending on its S 11, some power will be accepted by antenna and some power will be reflected back towards the source, next antenna when it is going to radiate, antenna is a metallic structure, inside we may have dielectric also so it is associated with some loss finally it is a passive component.

It cannot add any extra power, so that is a presented by antenna efficiency so finally than the total power whatever is radiated by antenna it is less than the power delivered by source. So we did not consider all these conditions when we derived this equation. Now so this is a simplified scenario, now we can represent this term in decibel scale, in that case it becomes a simple arithmetic addition and subtraction problem. So received power we can write down P t + G t + G r all are in decibel scale + 20 log of lambda by 4 Pie r, so this last term you see it depends on the separation between the antenna and the operating frequency lambda. So here are more points which we did not consider while driving it. First, r is much more compared to lambda so that we can consider it as a plane wave, then the antennas are arm obstructed.

No multipath propagation is there, no atmospheric scattering or attenuation effect is there, then antennas they are ideal which I discussed and are in right polarisation, bandwidth is narrow enough for single frequency consideration, this point also we discussed. Then this above condition, it can be achieved only in free space or in anechoic chamber, so that is why any antenna measurement is done inside anechoic chamber, where we do not have any external effect, we do not have any multipath effect or we do not have any reflection from wall effect. So let us then consider the effect of polarisation and the input impedance matching.

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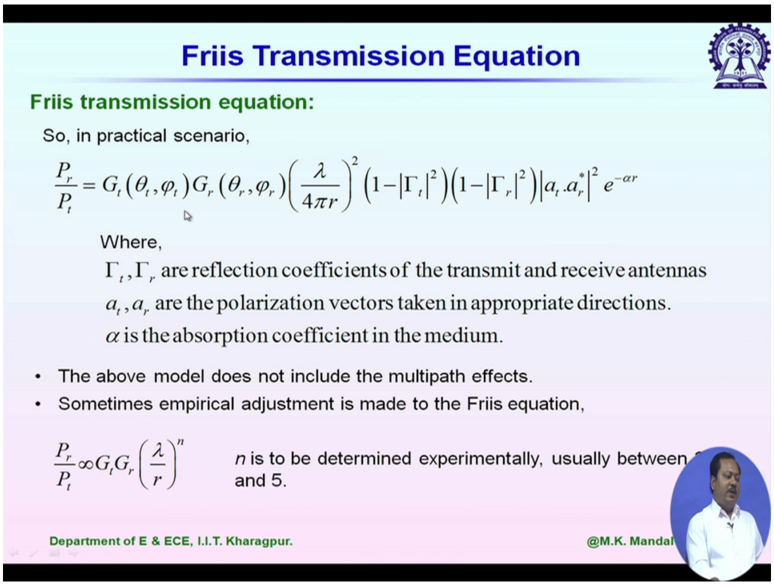

So we have a more practical form of series transmission equation, so P r by P t, this is equal to G t, now G t and G r it is a function of coordinate system, it depends on theta and Phi, so if the antennas are not aligned in their maximum beam direction, then we can take their actual gain value in that particular theta or Phi and we can put the values here. Then lambda by 4 Pie whole square into we are considering then the loss because of the matching problem, so 1 - Gamma t square, this is Gamma t square is nothing but S 11 of the transmit antenna. And similarly, Gamma r, this is S 11 of the received antenna, so and a t dot a r this whole square, so it is giving the polarisation vector multiplied by e to the power - Alpha r, so Alpha is the absorption coefficient in the medium.

So at least in this equation then we have included the effect of polarisation mismatch, the effect of atmospheric loss, the effect of reflection losses at the antenna terminal and also we represent gain of the antenna as the functions of Theta and Phi and we can consider the actual values facing to each other. But what are the factors which we did not consider in this equation, first of all we did not include any multipath effect in this expression so that is a huge problem because if I again consider that wireless communication system, whatever proposed or 5G, now we have to model properly any indoor situation, we can use our mobile phone inside any room also, so inside room we have reflection from furniture, walls, so we have multipath effect not from one single path, but from several path.

And it is really difficult to model this type of scenario particularly, this indoor scenario so what we do practically we do some measurement simply and try to fit that measured data by considering a typical n values, which will give minimum RMS error. So in that case then P r by P t, it is simply proportional to G t G r into lambda by r to the power n, so n value instead of 2 it is determined experimentally and typical value it can vary from indoor to indoor model to another indoor model and typical values between 3 to 5, not 2 but higher than that.

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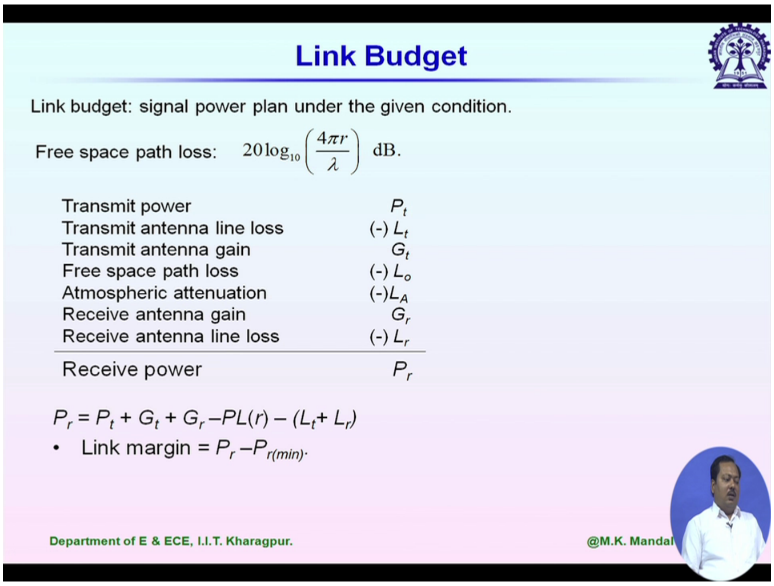

So now we are going to calculate link budget for a given wireless system. Some power let us say is being transmitted by transmitting antenna, then finally what power we are receiving at the receiver side. So the effect that mostly determined the received power is free free space path loss. It is given by 20 log 10 4 Pie r by lambda in dB, we got it from that free transmission equation and what are the other contributions? Transmit power P t, so if I increase transmit power what we expect, received power will increase. Next transmit antenna line loss, we will be using some cable or something to connect the microwave or millimetre wave source and to antenna and it is a passive device that source that cable and it will give some loss. So let us say that the loss at the transmitting side is L t and if the loss increases then transmitted power will be less and received power will be less.

Transmit antenna gain G t, higher is the gain so it will direct more power to receiver side so that is why its sign is positive, free space path loss expression is given above it is negative, if we increase separation path loss will increase, received power will decrease. Similarly, if we increase frequency that means decreasing lambda received power will decrease, we have a negative contribution, atmospheric attenuation again we have negative contribution, receive antenna gain just like the transmit antenna we have higher again, we have higher received power and then the finally received antenna line loss. So antenna received antenna it is also connected to receiver by using some sort of transmission line it will give you some loss, which is L r.

So in decibel scale then it becomes simply addition subtraction problem, so P r this is P t + G t, we are just following the sign. Now for a given link whatever power we are receiving that should be more than the receiver sensitivity. Let us say the receiver sensitivity is given by a minimum power P r min, now depending now you see whatever power we are receiving at a point it will vary with time due to fading effect, multipath effect and other effect. So we have to maintain a margin over that receiver sensitivity P r min, we call that margin as the link margin and it is given by P r - P r min. So for any given link then we have to calculate this P r and we have to see that many minimum link margin is being maintained or not, so typical suggested values is 3dB to 10 dB link margin for any given millimetre wave systems. Okay, so we will take a break then we will take a numerical value of link margin calculation, thank you.