Millimeter Wave Technology
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Module 7
Lecture No 33
Noise and Link Budget (Contd)

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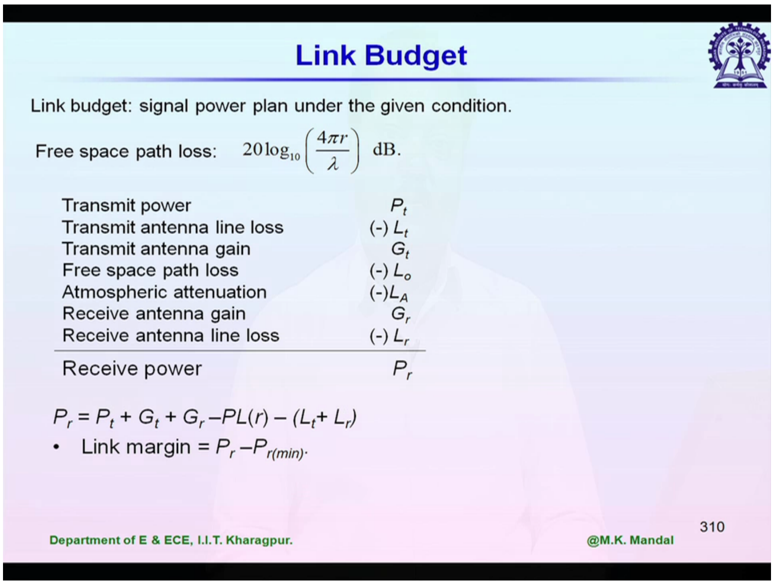

So we are discussing about link budget and then link margin and we concluded that at least a value of 3 dB to 10 dB link margin should be maintained for any given receiver system, so we will take one numerical example how to calculate link budget and link margin. So before that we will be using this formula simply, so here P l the function of r, this P l it represents actually the path loss, so here in the table free space path loss we are considering by L 0 and in decibels scale we represent it by P l r.

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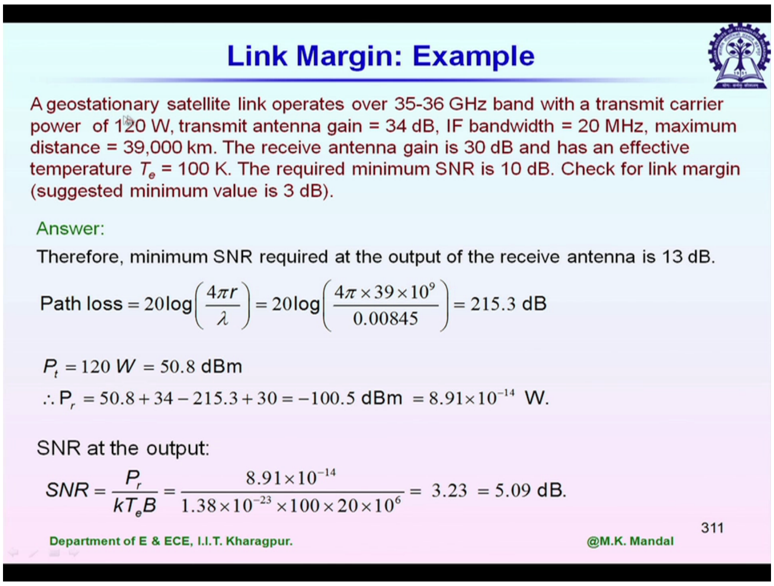

So let us say we have a geo-stationary satellite link that operates over 35 to 36 gigahertz band with a transmit carrier power of 120 watt, transmit antenna gain given as 34 dB, IF bandwidth 20 megahertz, maximum distance 39,000 kilometre, so it is a geo-stationary satellite so typical separation 36,000 kilometre, but it can change with time and here it is considered maximum value as 39,000 kilometre. Then the received antenna gain is given as 30 dB and has an effective temperature T e equal to 100 Kelvin, so what is the effective temperature we will discuss in next class after this. The required minimum signal to noise ratio SNR 10 dB, then we need to check now for link margin at least 3 dB value is there or not.

So what are the data given here, operating frequency if I go back to previous expression, transmitted power is given, gain of the antennas those are given, path loss we can calculate, for that we need lambda and the distance, distance is already given 39,000 kilometre, now lambda we will be considering the mid-band frequency that corresponds to mid-band frequency. No data is given for the line loss, so now simply we will neglect this term, then if I consider at least 3 dB link margin, so minimum SNR required at the output of the received antenna is 10 dB + 3 dB so 13 dB. Now we will check what is the received power P r, is it at least 13 dB or not. So we will start from path loss calculation, this is 20 log 4 pie r by lambda, r is given as the 39,000 kilometres, so it is 39 multiplied by 10 to the power 9 divided by lambda value 0.00845 meter, so you can calculate what is the free space wavelength at 35.5 gigahertz, it would come 0.00845 meter.

Now path loss in decibels scale then it comes to 215.3 dB. We will convert all this data to decibels scale; it will be easier for calculation than it would become simply arithmetic addition and subtraction problem. So transmitted power P t 120W, this is equal to 50.8 dBm, so dBm it is with respect to milliwatts power how we represent in dBm. Any power P, it is first simply divided by 1 milliwatts and then we take we convert it to decibels scale that is the unit we call dBm. So that means for this 120 watt how we can calculate it, you simply divide 120 divided by 1 milliwatts that means 120 divided by 10 to the power - 3, then you take 10 log of that value, it would come 50.8 dBm. Then the received power, this is the transmitted power so we are simply using this previous formula, only thing is that we do not have any value given for L t and L r and we are assuming them here as 0.

So if we put the values, it is coming - 100.5 dBm, we can also represent in terms of watt again, so just back to watt value, 8.91 into 10 to the power - 14 watt, it is so small the received power. It is a satellite link 39,000 limit of away, so SNR at the output so for this SNR calculation signal to noise ratio, so signal power whatever we are receiving that is P r 8.91 into 10 to the power - 14 and noise power, it depends on the effective temperature effective noise temperature T e of the receiver and the bandwidth of the receiver. So this bandwidth we will discuss later, again this bandwidth is not simply the bandwidth of the channel, for now we are considering bandwidth of the channel which is given as the IF bandwidth 20 megahertz.

So put the values here, place Boltzmann constant, which is 1.38 into 10 to the power - 23, so if I put the values here it is coming 3.23 or if I convert it to decibels scale 10 log 10, it is coming 5.09 dB. What was the required SNR, 13 dB and what we are getting here, 5.09 dB, so the receiver it cannot sense this incoming signal, then what is the solution? At least this SNR we have to improve to 13 dB, the only control where we have either we have to increase the transmit power or antenna gain, it can be transmit antenna, it can be received antenna, but we have to increase the gain. And another interesting thing that noise it depends on temperature, so we can pull down the receiver to decrease the noise component, so these are the external control we have, we do not have any control over separation, distance and IF bandwidth it depends on application so again we cannot decrease the IF bandwidth, so we have to only play with then with the transmit antenna gain, receive antenna gain, transmit power and the receiver temperature.

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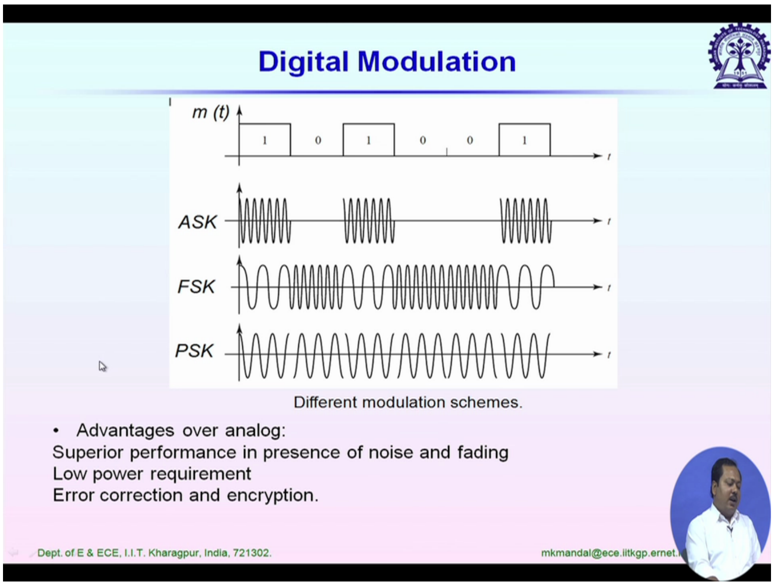

Next before starting the next part let us discuss the digital modulation, popular types of digital modulation. Digital modulation they are popular because they have certain advantages over analog modulation and from millimetre wave perspective we will discuss what are the effects we face with digital modulation? So why we use digital modulation, what are the advantages over analog modulation? It has superior performance in presence of noise and fading and not only that, if I compare the total power required for any transmission channel, it would have low-power requirement compared to any analog channel, this power requirement it depends on modulation scheme we will see. Then error correction, this is not only for digital modulation, for any digital system we can incorporate a way so that we can understand there is any error in received bit chain or not.

We can also encrypt our data which is not feasible in analog communication. So because of these many advantages now digital modulation it became very popular, inside your mobile phone or even any handheld devices mostly we are using now digital modulation and here are some typical digital modulation examples. The first one is amplitude shift keying or ASK, where simply 1 state will represent when the signal is present and 0 state will represent when there is no signal. So we have a bit here given by 101001 and now we are modulating it and representing it in ASK. The second one is Frequency shift keying; here we use two different frequency components to represent 1 and 0. You can see, 1 is being represented by lower value of frequency and the 0 component; it is being represented by higher frequency.

And in PSK we call it phase shift keying, a change from 1 to 0 is represented by a change in phase, a conventional PSK it will change the phase by 180 degree, we may use there are actually higher radar phase shift keying schemes like QPSK. In QPSK or Quadrature phase shift keying, we use 4 phase shift values; 0, 90, 180, 270 degree, we may have also higher radar coding higher radar modulation scheme using phase shift keying. In addition to phase, we can also control their amplitude in that case we call it Q A M or QAM signal. Now let us see how the bit error rate it varies with the signal-to-noise ratio of any bit.

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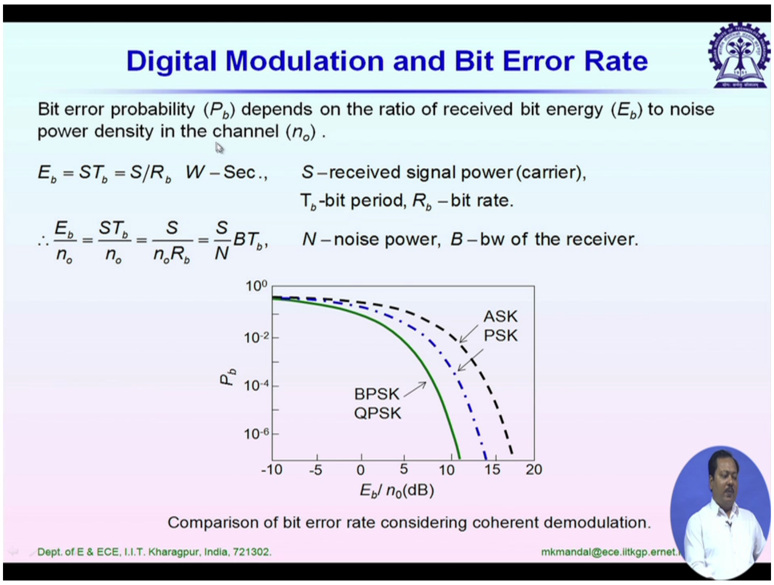

So bit error probability it depends on the ratio of received bit energy, received bit energy is being represented by E b to noise power density in the channel which is n 0. So E b, which is bit energy it is then S into T n, so S it is the received signal power, this is for the carrier in general. Or we can represent it in terms of bit rate, let us say R b is the bit rate then E b is equal to simply S by R b, this is watt second unit. Then SNR E b by n 0, this is equal to S T b by n 0 or we can also write down in terms of R b, S by n 0 R b and this is let us say B is the bandwidth of the receiver, then n 0 this is equal to total noise power n divided by B, so that it can be also represented as s by capital n, B into T b.

Now we see some theoretical calculation, comparison of bit error rate considering coherent demodulation, variation of bit error probability with E b by n 0 in dB for different digital modulation schemes. So for ASK what we see, for a given SNR value bit error probability is highest among these 3, or in other words we can say that for a specified bit error probability, BPSK or QPSK would require lower SNR value E b by n 0.

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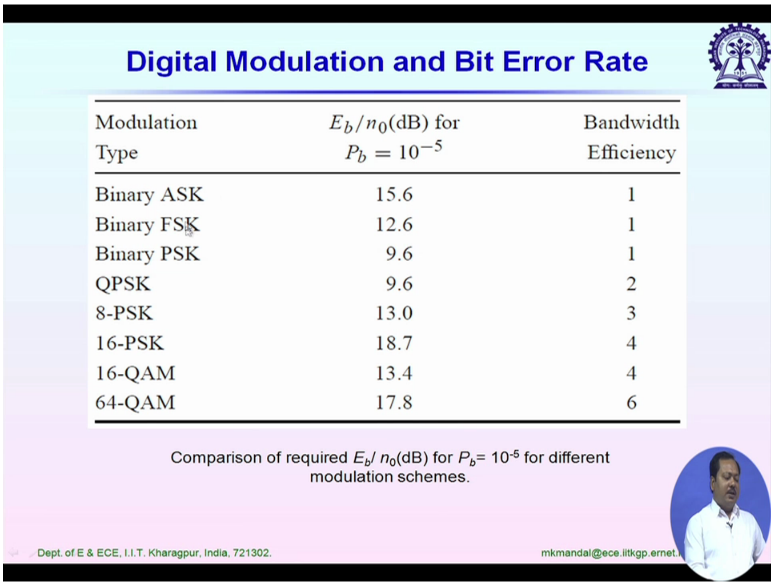

Here is the chart for different modulation schemes the minimum required E b by n 0 value for given bit error probability of 10 to the power - 5. So we want at least a bit error probability of 10 to the power - 5, then what is the minimum SNR we need to maintain for different types of modulation schemes. For binary ASK it is 15.6 dB at least, Binary FSK 12.6, so binary PSK and QPSK these 2 among all these for them we need minimum SNR signal power 9.6. If we go for higher order modulation schemes, again the required E b by n 0 increases, then why should we go for higher order modulation scheme? Because in that case the effective bandwidth or bandwidth efficiency we can say it can be increased.

Let us take one numerical example, so what we see before taking numerical example from this graph that if signal to noise power decreases, noise power it depends on temperature and bandwidth if noise so noise power more or less it will be constant, now if signal power decreases then what will happen, bit error probability it will increase error will be high. So for a given data rate, we need to maintain some minimum SNR for a given modulation scheme, so let us take now that example.

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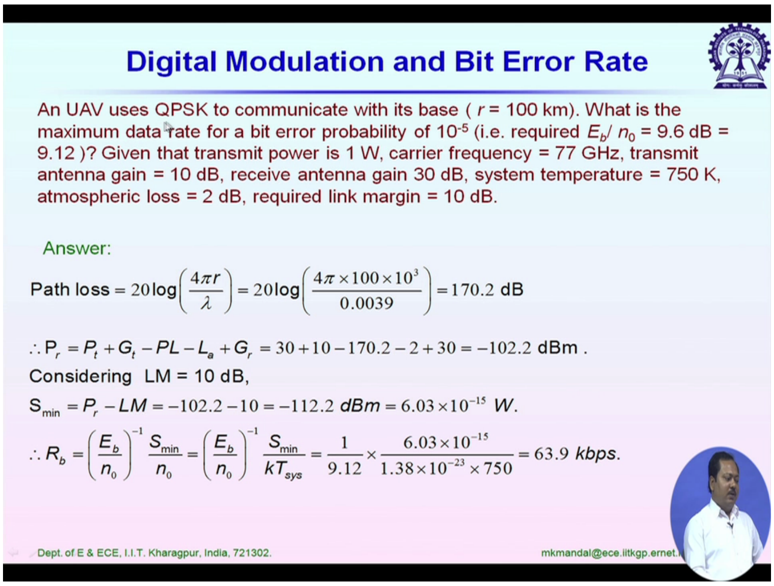

Let us say an UAV uses QPSK to communicate with its base station and base station is r equal to 100 km limit away maybe it is a flying object, then what is the maximum data rate for a bit error probability of 10 to the power - 5? So 10 to the power - 5 then what is the required E b by n 0 we have to first see from the chart, so E b by n 0 if I go back in this table it is given minimum bit error 10 to the power - 5 minimum E b by n 0 required is 9.6 dB, 9.6 dB if we convert it to simply ratio it is coming 9.12. Now other data, given that transmit power is 1 watt, carrier frequency is 77 gigahertz, transmit antenna gain 10 dB, receive antenna gain 30 dB and the system temperature 750 Kelvin, we also have some atmospheric loss 2 dB and required link margin is very high 10 dB.

You start from path loss calculation, path loss this is 20 Log 4 Pie r by Lambda, so r this is given 100 kilometres, so Lambda this is Lambda 0 at 77 gigahertz, which comes 0.0039 meters, if we put the values here, path loss is coming 170.2 dB. Now we calculate the receive power using previous formula, so P t transmit power is given 1 watt, simply we have to convert it to dBm, G t it is already in dB given 10 dB, G r it is 30 dB, path loss already we have calculated 170.2 dB and L a this term represents atmospheric loss, so since it is a loss of 2 dB, we are subtracting it, so putting all the values here, receive power it is - 102.2 dBm very small. Now considering link margin equal to 10 dB, so then you see this is the receive power then P r minimum specified for the receiver that P r min value it would be 10 dB down from this value or 102.2 - 10 it is coming in watt, if I convert it to watt 6.03 10 to the power - 15.

Then we calculate R b, just use this relationship, then R b it is E b by n 0 to the power - 1 into S min by n 0, so put the values here E b by n 0 we calculated here 9.12, so it is 2 to the power - 1, so 1 by 9.12 and S min we calculate 6.03 into 10 to the power - 15 by 1.38 into 10 to the power - 23 this is k into T, so T system temperature is given 750 Kelvin, do not mix with physical temperature so actual physical temperature it might be different so this is we call the effective noise temperature or simply system temperature, we will discuss this topic later. So it is 750 Kelvin, then this figure as a whole it is coming 63.9 Kbps. Even at 77 gigahertz for this given transmit power if we need to maintain all this required link margin let us say 10 dB and if we consider all these values than maximum data rate you see it is just 63.9 kbps.

So it depends on receive power in presence of noise, so SNR it plays very significant role, if you want to improve data rate then we have to increase SNR, we do not have any other option. Now till now we have discussed about the general characteristics and we have some idea about now SNR and how any channel it performs in presence of noise, we will take more examples and we will discuss about the effect of noise in details, so before that let us consider a special scenario because now people are talking about 5G communication and it can be of course at any millimetre and frequencies, but let us consider a typical scenario of 60 gigahertz band application because if we go for picocell, it is much easier to design or use at 60 gigahertz band then we can use that frequency reuse you can utilise that frequency reuse between different cells.

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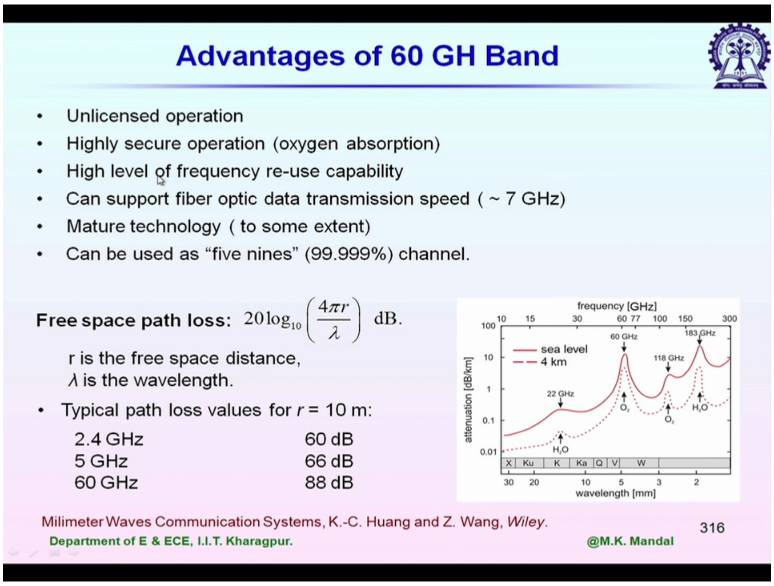

So what are the advantages of 60 gigahertz band, first of all throughout work it is unlicensed band 57 to 63-64 almost 7 gigahertz this is unlicensed band and highly secure operation is possible because of high atmospheric loss due to oxygen absorption. Why highly secure? Because whatever I am transmitting, I know it cannot go beyond a few kilometres, so a few after a few kilometres nobody can listen to me. Not only that, if I use a highly directive beam that means if the gain of my transmit antenna is very high, so any person outside that they cannot listen to me because it is whatever power available outside the main beam it is very less and it is further being attenuated by atmosphere, so we can say highly secure operation is possible.

Then high level of frequency reuse capability, we can decrease this size of picocell and we can utilise this same frequency band over and over, can support fibre-optic data transmission speed whole 7 gigahertz is available, so we can utilise almost whole of this band. Sometimes that is why it is called (())(24:14) channel. So you might have you might know the 2G spectrum distribution, 3G spectrum distribution, so for each and every company this spectrum available is very much limited. But if we go for 60 gigahertz band application, which you see it is unlicensed band, you can utilise the whole band and you will not disturb any other person who is a few kilometres away from you, so you can utilise this whole channel, 7 gigahertz channel is used so that is why sometimes it is called (())(24:52) usability. Then to some extent we can call mature technology because most of the components are available in market and day by day the cost becoming cheaper, but also we face some other problems.

So let us discuss about those problems, first problem we will be facing is free space path loss, which is 20 log 10 4 Pie r by Lambda, so r is the free space distance and lambda is wavelength. Now you see I am giving you some calculated values for this free space path loss for r equal to 10 meter. At r equal to 10 meter if I calculate this path loss for 2.4 gigahertz channel it is coming 60 dB. If I almost double the frequency to 5 gigahertz we have 60 dB more attenuation. Now if we go for 60 gigahertz application, path loss is 88 dB, in these expressions we did not consider the absorption due to oxygen molecule, no atmospheric attenuation is here. Just because of the lambda value, this smaller lambda value this path loss is increased from 60 dB to 88 dB, 28 dB higher.

So obviously for a same signal power at the same distance, if I compare the performance of a 2.4 channel with that at 60 gigahertz channel, what we expect SNR will be much poor at 60 gigahertz, so this is a problem for 60 gigahertz application. We have some other problems and we will take some numerical values considering this 28 dB extra attenuation due to path loss can really any channel or any communication feasible at 60 gigahertz or not, we will see after a break.