Introduction to Wireless and Cellular Communication

Prof. David Koilpillai
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture - 06
Wireless Propagation and Cellular Concepts
Introduction to Antennas and Propagation Models

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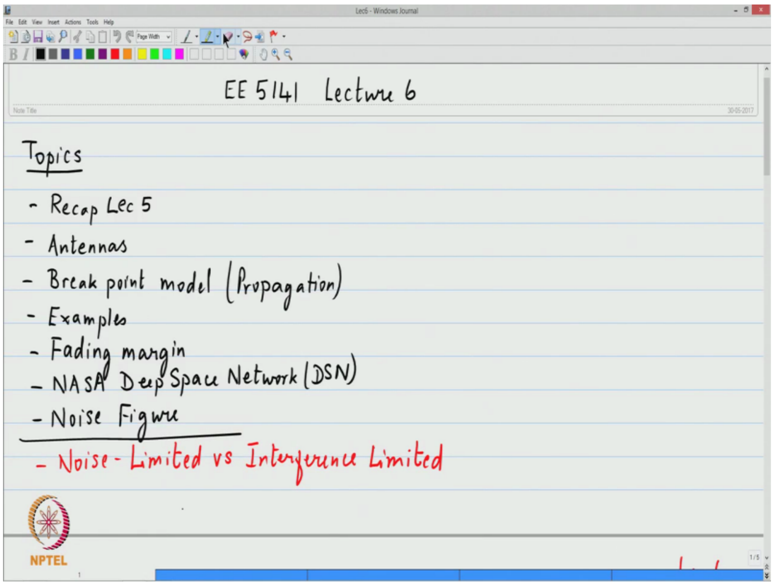

Good morning welcome to lecture 6, in today's lecture the topics that we will be covering are a quick summary of the topics that we have covered in lecture 5 and basic introduction to antennas leading to link to the propagation using the breakpoint model and in the course of today's lecture we will be having several examples which will highlight the concepts that we are discussing. The purpose of these topics is to work our way towards understanding the system design and 2 of the elements that will play a big important role in system design one is fading margin and another one is the noise figure.

Now, all of these concepts together help us to understand the noise limited systems that is when I have a transmitter the further I go away from the transmitter the noise the signal level decreases noise level being constant we find that eventually the noise becomes a limiting factor, and that is what we refer to as a noise limited system a system in which only the additive Gaussian noise is the only impairment. Now on the other hand when it is a cellular system we find that the noise is in addition to the noise we also have an impairment in the form of interference. So, that will be our entry point into our discussion on the interference limited systems and of course, in the examples you see that there is one example that we would like to discuss that of the NASA deep space network which is probably one of the most powerful antennas built in wireless communications and it is a very interesting and useful example for us to study, that is something that we will be looking at in today's lecture.

So, first we begin with a quick review of what is happened in the previous lecture and for that I would like to look at the main concepts that we had discussed in the last lecture.

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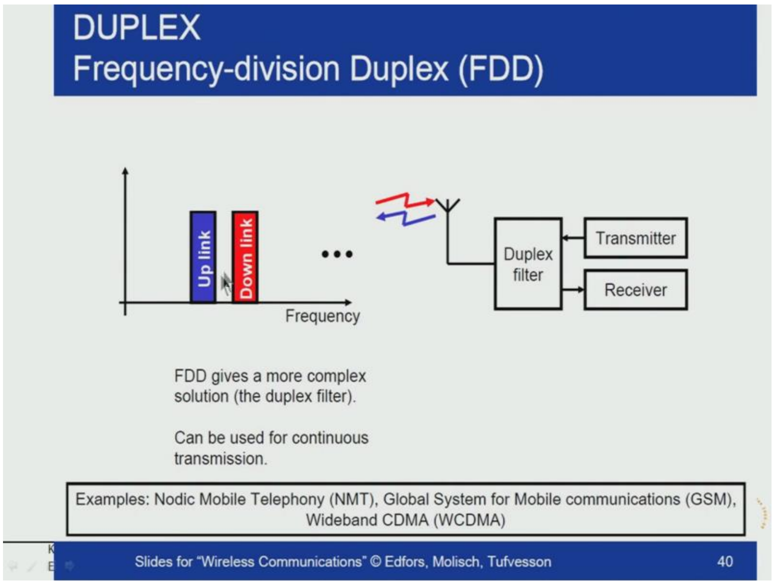

The concepts are that we can have the uplink and the downlink in the form of 2 different, in 2 different frequencies, this would be referred to as frequency division duplex and at that transceiver we have a single antenna that is used both for the transmission and reception and to separate the 2 signals we have the use of a duplex filter. Several examples of the FDD system for example: the GSM system that we use in the second generation, the wideband CDMA in the third generation or examples of a frequency division duplex system. Now on the other hand if you were to look at a time division duplex system.

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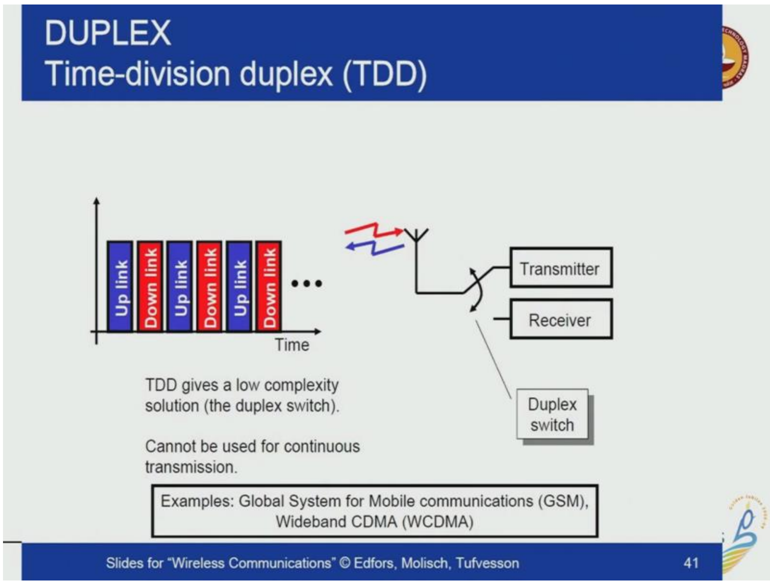

Now, in this case also we have a single antenna that is that is used for both transmission and reception; however, on the transmission side we find that the uplink and the downlink happen on the same frequency, they are happening on different time slots. So, this helps us to use the same frequency for both uplink and downlink by suitably sharing between the uplink and the downlink. So, in such a system you find that the structure is different we do not need a duplex filter because the transmitter and reception are happening on the same frequency and this is what we see in a TDD system. Now in example of a TDD system is the wideband CDMA version which has a TDD version of it. So, given these 2 basic examples I thought it would be good for us to have a summary of the systems that we have discussed so far.

So, let us go back to our notes and quickly pick up from there. So, we now have basic understanding of the FDD and the TDD systems.

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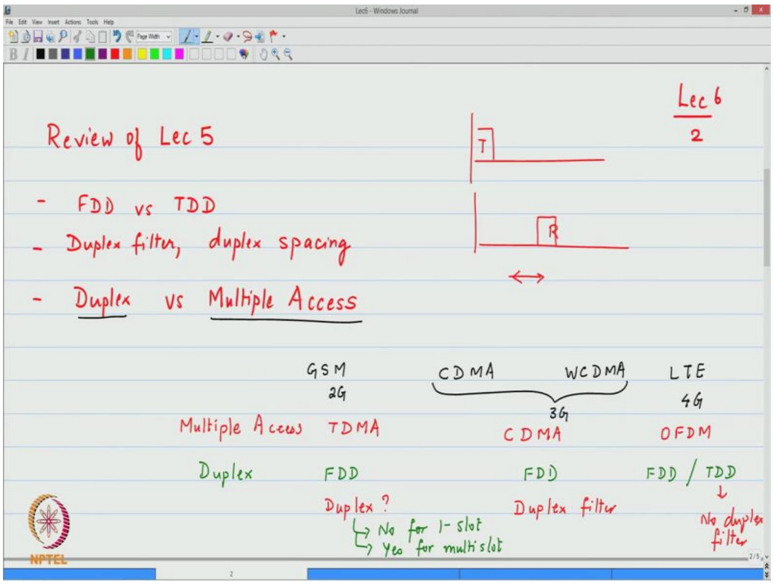

When a duplex filter is required and the spacing between the transmit frequency and the received frequency referred to as a duplex spacing. Now there is a fundamental difference or in terms of the duplex is what we call as the uplink downlink spacing versus multiple access sometimes this may cause some confusion. So, what I would like to do is just summarize what we had mentioned in the last lecture. So, we (Refer Time: 04:38) like to look at 3 different systems one of them is the GSM system, the second is the CDMA system, and then the third would be the wideband CDMA system and the LTE system the fourth generation. So, we have the second generation, we have the third generation and the fourth generation.

So, first I would like to address the aspect of multiple access; how is multiple access done in these different systems how are the different users sharing the common resources and in GSM it is done through time division multiple access each of the users gets a time slot on which they do the transmission and reception and therefore, that is a time division multiple access system. Now the CDMA system as the name suggests uses code division multiple access for sharing the resources between different users and the fourth generation the LTE system uses orthogonal frequency division multiplexing. So, 3 different multiple access methods in the second third and in the fourth generation, now we would like to take us next look at what is the frequency or the (Refer Time: 05:56) type of duplexing that is done.

So, the type of duplexing that is done decides the design of the transceiver. So, the duplex method that is used for GSM, GSM uses an FDD's duplexing frequency division duplexing, it the CDMA system uses a FDD system FDD also and the LTE the fourth generation can have an FDD or TDD system. So, the minute you have a TDD system you do not need a duplex filter. So, in this case we can straight away write down no duplex filter, no duplex filter on the other hand CDMA which is an FDD system it is continuously transmitting and receiving at the same time this requires a duplex filter, a CDMA system must have a duplex filter.

Now, by the definition of being in FDD system you would expect that GSM also has a requirement of a duplex filter. So, let me ask the question would a GSM receiver necessarily have a duplex filter? The answer comes in the following fashion in the case of a GSM system, the transmit and receive time slots are offset in terms of their time positioning. So, if I transmit at a particular time slot the receive time slot is offset with respect to the transmit time. So, the transmission and reception though they are happening on different frequencies are not happening at the same time. So, essentially because of this spacing between transmitter and receiver timing wise this essentially says that we do not require a duplex filter. So, TDMA in the case of GSM a duplex filter is not needed for a single slot operation because you can have them separated in this fashion.

So, the answer for this would be no for single slot for single slot operation. Now if you have a GSM transceiver which is using multiple time slots, then you may require the transmission reception may happen at the same time and there is a requirement that you would have a duplex filter. So, if you have a multi slot transmission then you will need to have a duplex filter. So, these are the basics that of the thing concepts that we have discussed and with this we would now like to dive into the topics of today's lecture. So, the first topic that we would like to pick up is to have a basic understanding of antennas, now antennas is our ability to transmit or receive electromagnetic radiation and is a topic that is studied extensively in electromagnetic theory our interest is to understand it from a systems perspective.

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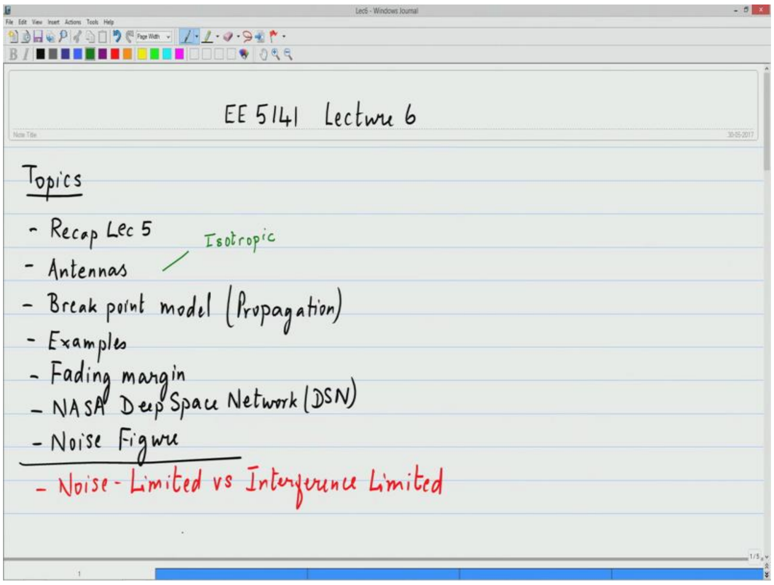

So, the first concept that we would like to introduce in the topic of antennas would be the topic of isotropic antenna. It is a concept that helps us understand the behaviour and the property of antennas. So, this is our concept such a antenna does not exist physically, but it helps us to explain the basic behaviour of antennas and also for us to understand the system impacts that these antennas will have.

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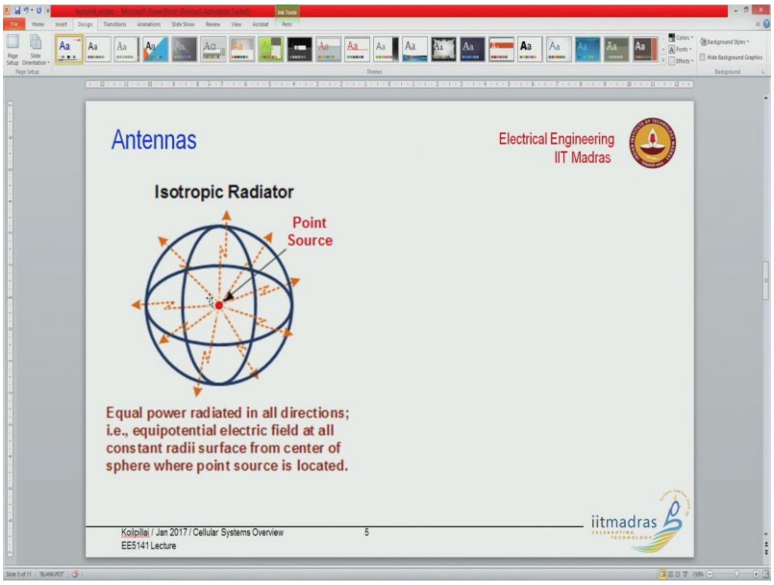

So, the isotropic radiator I would like to explain it in the context of a diagram and the isotropic radiator you can think of it as a point radiator it is a point radiator from which the radiations emanate in all directions in 3 dimensions. So, it is a 3 dimensional radiator and it is a point source it radiates in all direction. So, this is one of the basic concepts that we use in our understanding of antenna. So, an isotropic radiator.

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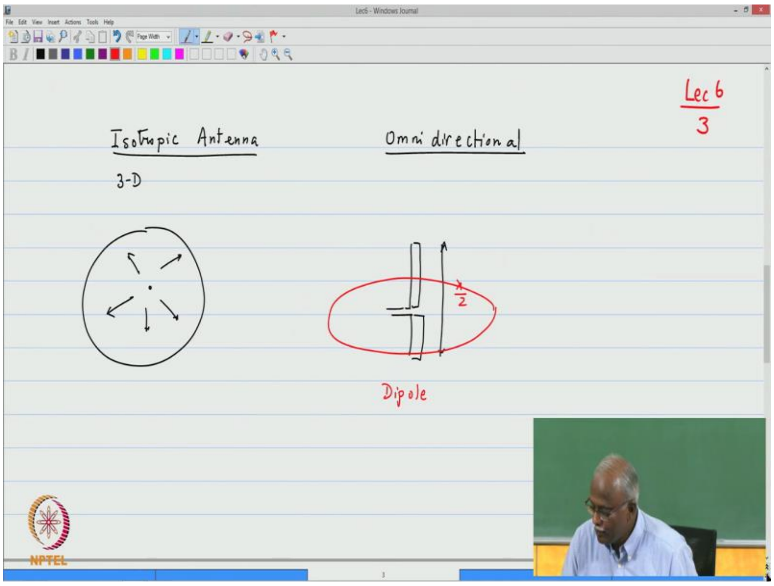

Now, how do we incorporate this into our design? Basic explanation of isotropic antenna, isotropic antenna; it is a 3 dimensional radiating element it radiates in all directions and it is one that we use for a explaining in a conceptual manner. So, in contrast to this we have a Omni directional antenna, Omni directional antenna now this antenna has got a property that is different from that of an. So, if you think of the isotropic radiator as a 3 dimensional radiator in all directions, the isotropic antenna. So, basically the isotropic antenna radiates in all directions.

The Omni directional antenna we think of it primarily in the context of a dipole antenna, typically the size of it would be of the order of lambda by 2 this would be a dipole antenna and this has a radiation pattern that is equal in it is in the horizontal plane in the azimuthal plane. So, the radiation pattern is equal now it is not equal in the vertical direction. So, we will come to describe that in a little bit (Refer Time: 11:36). So, we have isotropic antenna Omni directional antenna isotropic and Omni directional are not the same. So, in the initial part of our lecture we are going to be looking at the isotropic antenna.

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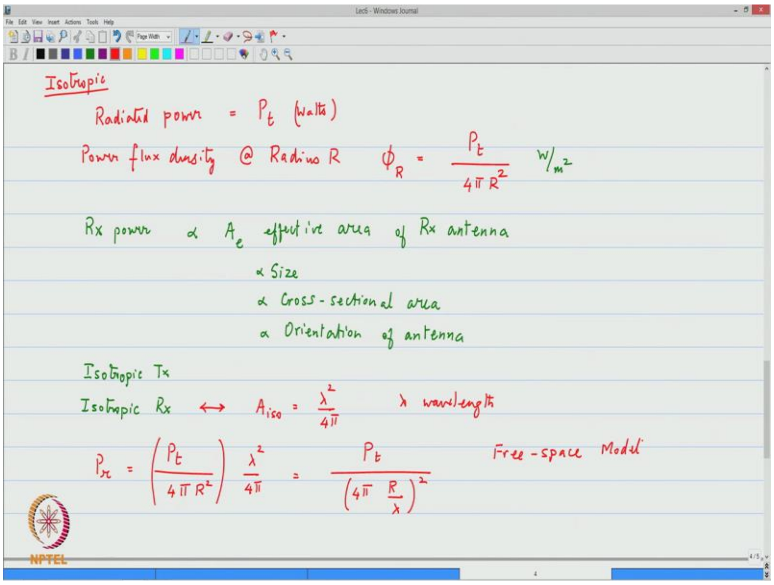

Now, if we have a radiated power, radiated power of P watts. So indicate that as p subscript t transmit power this is the transmitted power. So, we define for this antenna for a isotropic radiator; isotropic antenna is our point topic of discussion now, the power flux density this is the total power that is radiated experienced at a unit area at a radius R. So, power flux density at a radius R radius from the point source radius R, this is denoted by phi subscript R and this is given by the transmit power divided by area of the sphere since we are radiating in all directions 4 pi R square and the units would be watts per meter square .

Watts per meter square that is the power flux density and this tells us how much of is the intensity of the radiation when you are at a distance R the number of the flux intercepted per unit area. Now if we were to look at the other side of it from the transmit side to the receive side, the received signal power of course, the ideal scenario would be is if you could have a circle antenna in enveloping the entire transmit entire power flux density, but such a receive antenna is not practical. So, the received signal power is proportional to the area that you can with which you can intercept the power flux density. So, A e stands for the effective area, effective area of the antenna that area of the receive antenna effective area of the receive antenna.

So, this is what tells us what portion of the transmitted signal power can be effectively intercepted. Now the effective area basically (Refer Time: 14:07) depends on some elements, it first of all depends on the size of the antenna the larger the size a larger it is effective or effective power that it can in the effective power that it can intercept. So, there is a proportionality to the size, it is also proportional to the cross sectional area cross sectional area; the cross section that will intercept the transmitted power that is a cross sectional area and of course, it is also dependent on the orientation of the antenna because you need something that is sufficiently large with a good cross section and pointed in the direction. So, that it can intercept the (Refer Time: 14:56) the (Refer Time: 14:56) transmitted power (Refer Time: 14:58).

And these are 3 elements that will affect the effective in the or reception of a signal. Now we have the power flux density which is P t by 4 pi R squared, now the power flux density multiplied by the effective area of an of the receive antenna is going to be my received signal power. So, if we assume that we also have just like we had an isotropic transmitter we had an isotropic transmitter, that we also have a isotropic receiver a point source isotropic receiver. Now in the in the in the theory of antennas we (Refer Time: 15:46) associate with an isotropic receiver an effective area of an isotropic receiver as a lambda squared by 4 pi.

You can think of it as a constant that that is used for understanding the basic operations. So, where lambda is the wavelength, wavelength in meters wavelength of the (Refer Time: 16:12) or that (Refer Time: 16:12) transmitted electromagnetic wave and a 4 pi is a constant dimensionally consistent because lambda squared would give you a meter squared and that corresponds to the effective cross sectional area. Now the received signal power in the case of an isotropic transmitter isotropic receiver would now can now be written as the transmitted power divided by 4 pi R squared as the effective or the power flux density multiplied by the effective area of a isotropic antenna which would be lambda squared by 4 pi and this can be written into a convenient form P t divided by 4 pi R by lambda whole square.

Now, this is a very very useful result because this is what we referred to as free space propagation, where we have an isotropic transmitter and isotropic receiver and we have effectively line of sight transmission in free space between the transmitter and receiver. So, this is the free space model and this also gives us a very useful form with which we can work.

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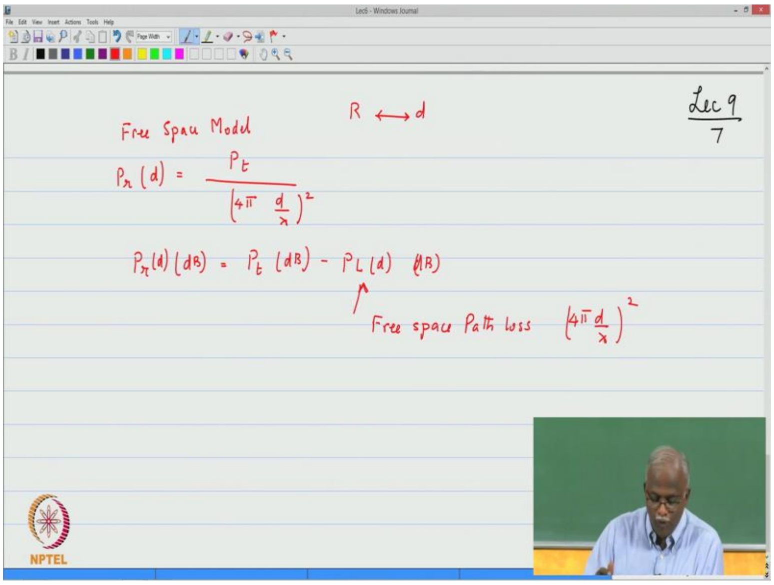

So, let me recap the free space model free space propagation model it also called the free space path loss model (Refer Time: 17:43) referred to as a free space model. So, the transmitted signal power or the received signal power we initially we referred to the power flux density at a distance R and typically when we talk about transmission we do not talk about the radius of transmission.

But more at distance of transmission from the transmitted receiver. So, we going to be make a change of variable from R to d, so that we can refer to it in terms of the distance between the transmitter and receiver. So, the received signal power at a distance d can be written as the transmitted signal power divided by 4pi I have replaced d r with d, d by lambda whole square and writing it in dB the received signal power in decibels at a distance d represented in decibels is given by the transmitted signal power in decibels and what is the difference between the received signal power and the transmitted signal power is the path loss we call that as P L stands for path loss at a distance d also expressed in dB.

So, this quantity which is the path loss is the is referred to as the free space path loss free space path loss and it is given by 4 pi d by lambda whole squared and of course, this can be expressed in (Refer Time: 19:23) in dB if you want to express the path loss in dB. So, this is a very good way for us to understand how the free space path loss a path loss works. So, what I would like to do is work do compute a simple worth example to help us consolidate whatever we have understood with the free space model and then we will try to build on this going forward.

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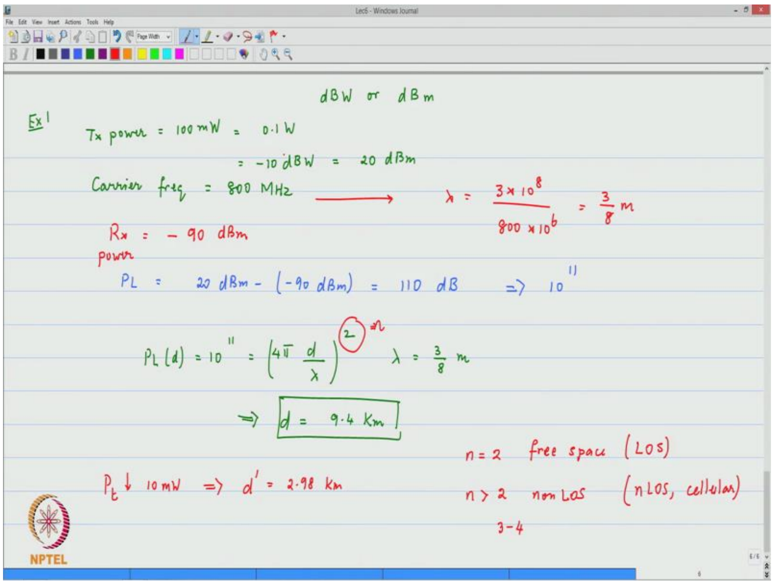

So, the first example would be that I have a system where the transmitted power transmit power is given as 100 milliwatts; 100 milliwatts is my transmitted power. Now I would like to convert this into dB scale. So, power if I want to convert into dB scale can be expressed as dB W or as dB watts or dBm which stands for dB milliwatts. So, the conversion this would be 0.1 watt. So, 100 mille watts divided by a thousand point one watt this can be written as minus 10 dB w or if I were to convert it in from dB w to dBm always have to add plus 30 which can also be converted directly from 100 milliwatts converted into dB would be 20 dBm. So, 100 milliwatts can be represented either as minus 10 dB w or s plus 20 dBm.

Now, we are given that the carrier frequency for the electromagnetic transmission carrier frequency is 800 megahertz and this will help us compute the wave length. So, the wave length would be the velocity of light 3 into 10 power 8 divided by the carrier frequency 800 into 10 power 6 that gives us 3 bar 3 8 of a meter; and we are told that the received signal power received signal power is minus 90 dBm received signal power is minus 90 dBm.

Now if by any chance you made a mistake and you wrote down the received signal power as plus 90 dBm, the minute you see it you should definitely it should strike you because my plus 90 dBm would be a very large value of power, because it is its 10 power 9, 10 power 9 dB 10 power 9 milliwatts. So, which means it is a large number of amount of power. So, typically the received signal powers that we are working with of the order of minus 90 dBm much much less than a milliwatt. Now the difference between the transmitted power and the received power is the path loss. So, that tells me that the path loss is equal to 20 dBm minus of minus 90 dBm this gives me 110 difference of 2 dBm quantities or the ratio of 2 powers is a dimensionless quantity. So, this is 110 dB please do not write it as dBm it is a 110 dB because it is a ratio of 2 powers.

So, the path loss in dB is 110 and this effectively corresponds to on a linear scale 10 to the power of 11 which is a very large number. Now we would like to know what is this correspond to in terms of the distance. So, if you write down the expression for path loss, path loss at a distance d we are given as 10 power 11 like to recreate it to 4 pi d by lambda whole squared substitute for lambda where lambda is equal to 3 by 8 of a meter, you can verify that the distance that we can get will be approximately 9.4 kilometers. So, this is what the free space propagation loss tells us, and is a very useful measure for us to know that if there is a isotropic transmitter and isotropic receiver and only free space between the 2 of them 100 mille watts of transmission we could reach all the way up to 9.4 kilometers, and still give you a received signal power which is of the order of minus 90 dBm.

It is also helpful for us to make a note that because of the exponential term in terms of the distance, a small change in the power does affect the distance also. So, if the transmitted power was reduced to 10 milliwatts you can redo the calculation and we find that the distance at which you can achieve minus 90 dBm is now only 2.98 kilometers, so the non-linear relationship between a tenfold in the decrease in power translating into a distance. Now an important point to mention which is helpful for us to keep in mind is the fact that free space we write it with an exponent of 2 this is writing of this as a path loss exponent n equal to 2 is for free space.

Typically in a cellular system there is non-line of sight as opposed to free space propagation, free space propagation will be line of sight. So, cellular is non line of sight and as you would expect the losses are more in a non line of sight system. So, n is typically greater than 2 for a non line of sight system. So, if you have non line of sight system and typically it is in the range of 3 to 4 which tells us that the losses will be much more significant when you traverse a distance d. So, with the same transmit power you will be able to in a non line of sight environment you will be able to transmit the signal to a shorter range as compared to a line of sight system.

Now, this also leads us to is the propagation model which is very helpful for us in terms of understanding the entire system.

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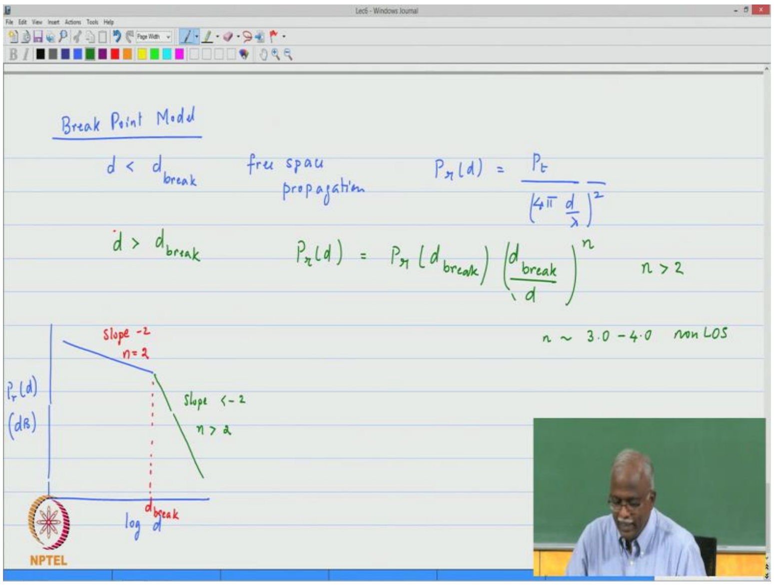

So, this would be the breakpoint model; breakpoint model the breakpoint model says that there are 2 regions in your signal propagation, this is a 2 two a single breakpoint model and it says that if I am below the breakpoint, then I can assume that it is free space propagation. Free space propagation and my exponent they receive signal power at a distance d is given by the transmit signal power by 4 pi d by lambda whole square.

So, this would be my free space propagation before. So, if I were to sketch it plotting the received signal power P r at a distance d measured in d B, as a function of log of the distance then up to a certain point which is the break point, I see a slope which is minus 2 or a path loss exponent which is n equal to 2. So, this is the basic model up to this is the d break, break point. Now once we go beyond the break point for d greater than d break the relationship is given in the following way, the received signal power at a distance d beyond d break is the received signal power at d break into d break by d raised to the power n where n is typically greater than 2 that is when you have the non line of sight component.

Now, let us make a quick check to see if this is how this is working; if n had been equal to 2 then we would have still have had the same expression as free space propagation; however, when you have an path loss that is greater than 2 for d break, you find that beyond this break point you find that the path loss exponent causes the receive signal power to decay much faster. So, here we have a slope that is more negative than minus 2 or a path loss exponent that is greater than 2.

So, basically we find that the received signal power decay is much faster as the distance increases. So, this is essentially the breakpoint model and typically the path loss exponent can be anywhere from 3 to 4 for non line of sight environments, and this is a way by which we can have a first quick prediction of what the received signal power is likely to be ok.

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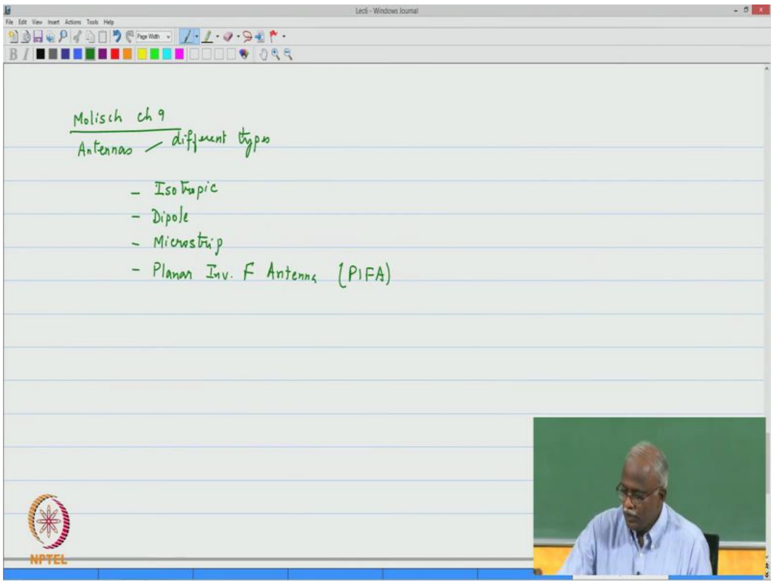

Now, I would like to go back and quickly explain a few elements about the antennas and make before that let me also suggest that for this portion a good reference would be Molisch chapter 9, which has a good systems level description of antennas the different types of antennas and their construction and their basic properties different types, and it is very useful for us to we are only talked about a isotropic antenna and in a very very limited sense the Omni directional antenna.

But there are several types of antennas let me just mention some of those. So, we have the isotropic that is our conceptual description of how the radiation occurs then we have the dipole antenna, then in Molisch chapter 9 you can see that there are several other types of antennas which are used in our cellular systems something called a micro strip antenna micro strip antenna there is a planar inverted f antenna inverted f antenna very commonly used antenna.

It also referred to as PIFA planar inverted f antenna and so there are several flavors of them which you can see and understand their properties, but very important for us to understand that at the end of the day what we are looking for is the effective cross sectional area we are looking for the ability for the antenna to transmit and receive signals in a suitable direction. So, let us quickly take a look at the isotropic the Omni directional antenna and then. So, if you were to look at a dipole antenna which would be a basis for discussion on Omni directional antennas.

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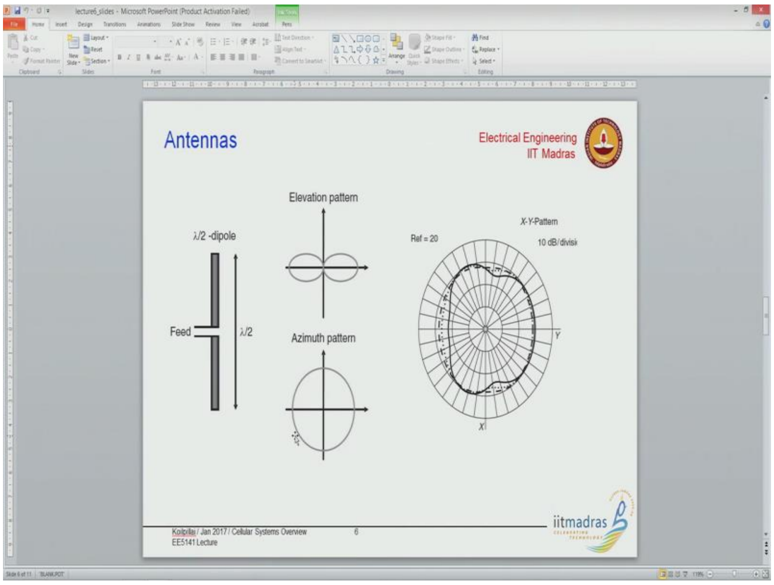

Now, if we were look at the radiation pattern ideally in the horizontal direction all 360 degrees the antenna radiates equally, but the minute you look at the elevation side you find that the antenna is radiation pattern is very different it is not radiating like an isotropic radiator. So, for example, if we were to look at the radiation along the dipole axis at a point above that, you find that there is almost no radiation at this point similarly at a point below the dipole axis also you would find that there is no radiation. So, that is what is reflected in terms of the radiation as a function of elevation. If the angle is 0 measured with respect to the vertical the elevation angle being 0 size that the radiation is there is no radiation in the angle 0 no radiation at angle plus or minus 180 degrees, and the maximum radiation occurs in the plane that is perpendicular to the dipole axis and that is what you see in terms of the peak of the radiations.

So, this is different from the isotropic radiator, but it has got a very useful property that in the azimuth you find that the radiation pattern is more or less equal. Now based on how the antenna is mounted you may find that this Omni directional pattern is sometimes disturbed and it is slightly deviates from the Omni directional behavior and that is something that is to be expected because this is this would mean that there is no other metallic objects or obstruction. So, that you get a perfect pattern, but the property that we use in most of our cell phone devices is that the antenna should have a Omni directional radiation pattern and the reason for that is first of all we do not know in which direction the base station is. So, irrespective of our orientation we want the signal to be able to reach the base station. So, an Omni directional radiation pattern is something that is very desirable in the handset of a cellular system.

On the other hand when we talk about a base station as we saw in the last lecture, initially we concept we talked about base stations that could radiate in all directions, but when it comes to practical deployment we find that it the practical way to deploy a base station would be to have radiation in a sector, and typically the sectors that are used in a cellular system is about 120 degrees in terms of the.

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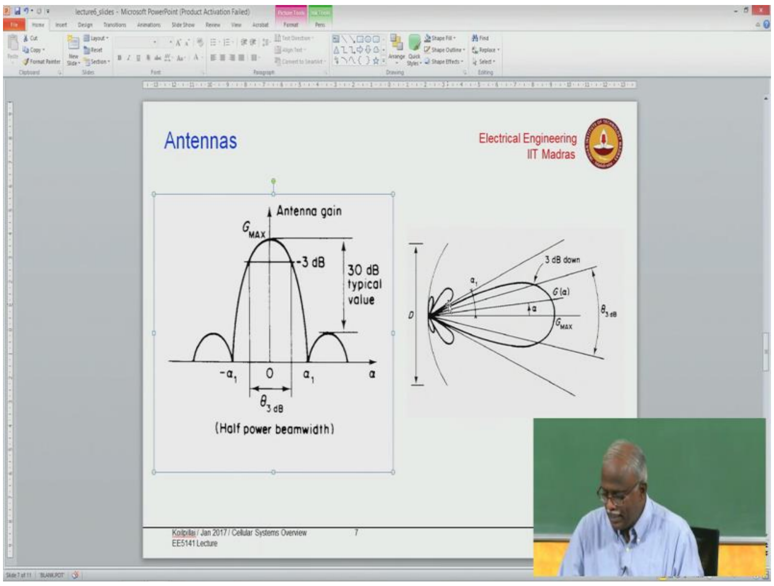

So, when we start talking about a directional antenna like a base station antenna, then we find that we can now talk about a radiation pattern. This is not a Omni directional antenna it has got a very specific radiation pattern it has got a direction of maximum gain and then as you move away in terms of angle from the point of on the direction of maximum gain.

You find that the gain eventually starts to drop and we are very interested to find that angle at which the power drops to minus 3 dB. So, typically we would like to use that as the main direction of radiation and this region where (Refer Time: 35:13) the transmitted gain is between maximum and minus 3 dB of the maximum as what we refer to as the beam width or the half power beam width or the range in which they are that angle in which the antenna radiates. So, typically we would like this to be of the order of 120 degrees for a sectored cellular antenna.

Now, we find that in any practical antenna you will find that the radiation will extend beyond the main beam width and of course, we would also there may be also be some side lobes, now radiation outside of the main beam width and the side lobes are undesirable and we would like to keep that as small as possible to get the maximum amount of radiation in the direction of interest.

So, this is how the directional antennas are designed and the main difference between a base station antenna which is directional and a handset antenna which is Omni directional. So, with this we have a basic understanding of the antennas, what we would like to do is pick up and look at some additional examples in the context of the system that we are working with. So, let us go back to our examples and we will take up, we will take up an example that we can look at and understand how the system works. So, this would be a practical example that we would like to study.

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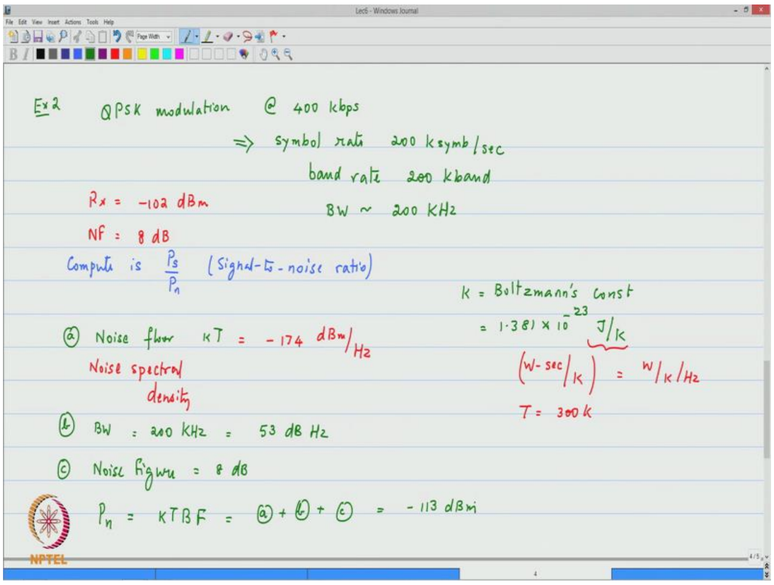

So, we are told that this is example 2 of our system we are told that we are using a QPSK modulation.

QPSK where each bit or each symbol carries 2 bits of information. So, QPSK modulation at a rate of 400 kilo bits per second. Now QPSK at four hundred kilobits per second says that my symbol rate since I am transmitting 2 bits per symbol, symbol rate is 200 kilo symbols per second kilo symbols per second this is also referred to as the baud rate where the baud rate is 200 kilo baud. Now this is a basic definition of a system one thing that the baud rate always tells us is an estimate of what is the bandwidth that you would require to transmit the system. So, typically a 200 kilo baud or a 200 kilo symbol transmission would require a bandwidth of the order of 200 kilohertz.

So, I have assuming that you have done a proper pulse shaping at the transmitter then you should be able to fit it in a bandwidth that is of the order of 200 kilohertz. Now some additional information that is given to us the received signal power is minus 1 o 2 dBm, where also told that the noise figure of the receiver is 8 dB. So, now, we would like to be able to understand how the system or the receiver is being designed. So, the question or what we are asked to compute is what is the received signal to noise ratio. So, in a practical system we would refer to the signal to noise ratio in terms of the signal power to the noise power. So, signal to noise ratio.

So, what is the signal to noise ratio for such a system having already talked about the how the antennas work, now we want to understand the impact that it will have in terms of this system. So, the first step that we would like to do a recall what we have done in the last lecture would be the following calculation. So, the first step would be the noise floor trying to estimate what would be the noise floor. So, the noise floor for the receiver noise floor for the system is given by k times T where k is the Boltzmann's constant Boltzmann's constant as we have introduced in the last lecture Boltzmann Boltzmann's constant.

And it is given by one and it is value is 1.381 into 10 power minus 23 joules per Kelvin. Now we are talking about watts and hertz that is what we have in our input parameters. So, I want to be able to move from joules per Kelvin in to things at we can work with. So, in terms of just interpreting the units of the Boltzmann's constant it is helpful for us to visualize joules per Kelvin in the following way, joules is energy which is the power into time. So, I can write joules as watts seconds per Kelvin, and this can also be written as seconds can be written hertz is one by second.

So, this can be written as watts per Kelvin per hertz. So, now, if I multiply k by T then what we get is watts per Kelvin hertz multiplied by Kelvin. So, I get watts per hertz as the noise spectral density. So, noise spectral a noise spectral density noise spectral density which is k t is given by noise spectral density (Refer Time: 41:37) multiplies k times T this is a calculation that we you can substitute and obtain with a the 300 Kelvin if you take it at temperature to be 300 Kelvin then we can get minus 174 dBm per hertz, dBm per hertz basically you have converted it into a dB expression.

Now, the second term that we would like to incorporate in order to estimate the noise floor would be bandwidth of the signal the bandwidth of the signal and since we are having a 200 kilowatt system and an equivalent bandwidth of 200 kilo hertz then we can take the bandwidth to be equal to 200 kilo hertz, which if you express it in dB will be 53 dB hertz and the third element is the noise figure noise figure which is 8 dB. So, the noise power that we will encounter in the receiver will be k T B times F, the noise power is given by k T B F, k T B in the noise spectral density being the bandwidth of the signal F being the noise figure.

So, this is when you are doing it in a dB scale it will be a plus b plus c which is given by (Refer Time: 43:23) estimate the compute the answer minus 113 dBm minus 113 dBm.

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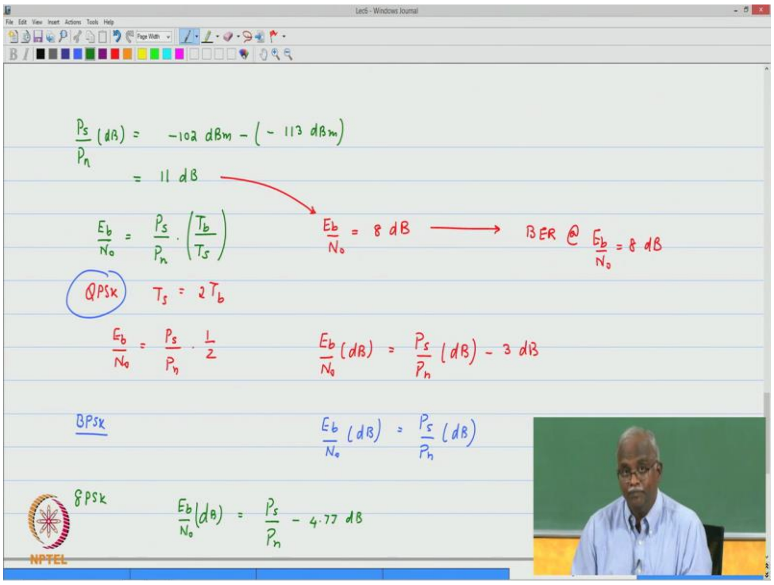

So, if you now look at the received ratio of the received signal power to the noise power in d B, this will be we are told that the received signal power is minus 102 dBm minus 102 dBm minus of minus 113 dBm. So, this gives us a P s by P n of 11 dB again remember it is a ratio of power. So, the answer should be in dB.

Now, a very interesting observation and an extension to what we can learn from this particular example is to translate P s by P n the signal to noise ratio into the parameter that we are very familiar with in digital communications which is E b by n naught as we have discussed in the last lecture E b by n naught is given by in terms of P s by P n is equal to E b by naught is equal to P s by P n into T b by T s or the ratio of the bit duration to the symbol duration. Now for QPSK symbol duration is equal to 2 times the bit duration because each symbol are carries 2 bits of information.

So, t b by t s is a factor of one by half. So, E b by n naught is equal to P s by P n into one half and if I were to express it in d B, E b by n naught dB is equal to P s by P n in dB minus 3 dB. So, in this particular example for QPSK, E b by n naught would be corresponding to 8 dB and for this I am sure each of you can look up a standard textbook like (Refer Time: 45:42) and tell me what will be the bit error rate at E b by n naught equal to 8 dB ok.

Now, when we look at b r curves we always are interested in the context of E b by n naught we are not talking about P s by P n, but in a practical system we measure the received signal power we know what is a noise power and therefore, what is easy for us to compute this P s by P n. Now extending it just a little bit more for to reinforce the concept now instead of QPSK if the system had been BPSK would anything have changed in terms of the P s by P n assuming that we still had the same expressions before us what we would find is that the relationship between E b by n naught. E b by n naught for BPSK would be P s by P n in dB. So, if you achieved 11 dB P s by P n it would translate to 11 d B, E b by n naught. So, for a given P s by P n signal to noise ratio in terms of signal power to noise power you will find that the E b by n naught for a QPSK system is 8 dB, for a BPSK system is 11 dB there is a difference between the 2 and therefore, you would find that the corresponding BPSK system would have a better B E R.

Now, this may seem a little counterintuitive because we are always told that QPSK and BPSK are the same performance keep in mind it is the same performance with respect to E b by n naught. Now E b by n naught translates differently to P s by P n when it is BPSK and then when it is QPSK. Now just for one more one more illustration if it had been 8 P S K. E b by N naught in dB would have been P s by P n in dB the t b by t s now would be a factor of one by 3 and if you were to converted into dB scale this would translate into minus 4.77 dB. So, keep in mind that this is the way that we would like to understand.

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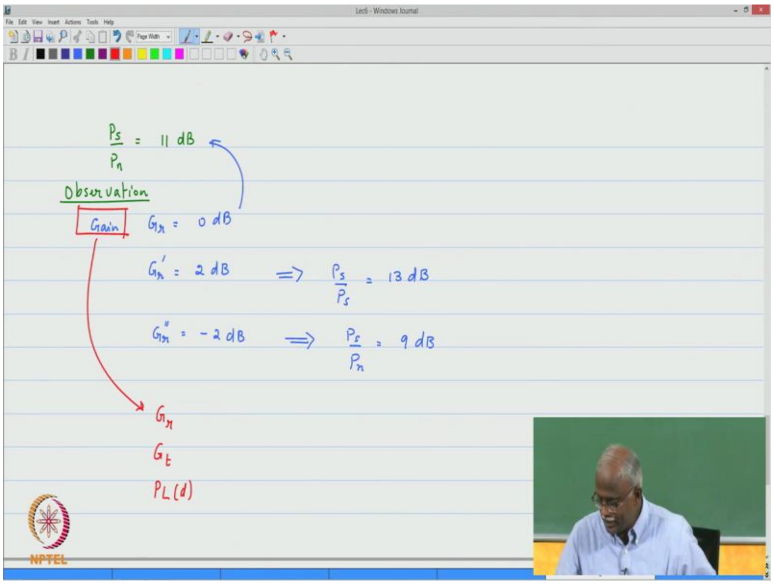

Now, in addition to all of this we now also have to make a note of the following now we achieved a P s by P n of 11 dB that is what we have been able to achieve. Now if you make the following observations the following are observations regarding the factors that affect that the p the value of P s, now if the original system had been designed to have a gain of 0 dB for example, the gain of the receive antenna to be 0 dB and we achieved a P s by P n of 11 dB let us say the that was how it was designed.

Now, if I am able to increase the gain of the receive antenna G r dash to 2 dB, a gain of 2 dB on the receive antenna then this would directly mean that the P s by P n would be whatever was the original P s by P n the signal power whatever I received previously will now increase by a factor of 2 dB. So, this would become 13 dB. So, there is a positive impact if you are able to increase the transmit gain or the receive gain in terms of the received signal to noise ratio. On the other hand if you would reduced the received gain to minus 2 dB of course, this would naturally be P s by P n would be instead of 11 dB now it would be 9 dB.

Now, you may be wondering what would be a scenario where you would implement a gain of minus 2 degree, actually we do not deliberately intend to gain introduced a gain of minus 2 d B, but what typically happens is that if you have a cell phone and it is designed with let us say 0 dB d b antenna and the 0 dB gain antenna. So, when you hold it in such a fashion that your hands are covering the antenna then you could find that the tissue can actually cause a further loss of signal. So, effectively the gain of the antenna instead of being 0 dB becomes minus 2 dB. So, this is not n by design it could be by because of the way it is used that the signal. So, we need to keep in mind that when we design the system we do have to keep a close watch on what is the gain that we are able to achieve, this gain can be in terms of the transmit antenna it can be in terms of the receive antenna and we also are very keen to monitor what is the path loss because what is between what is transmitted and what is received the path loss makes a big difference.

Now, to conclude today's lecture, I would like for you to look at the following example and maybe once you can have a chance to read it we will pick it up from there in the next lecture.

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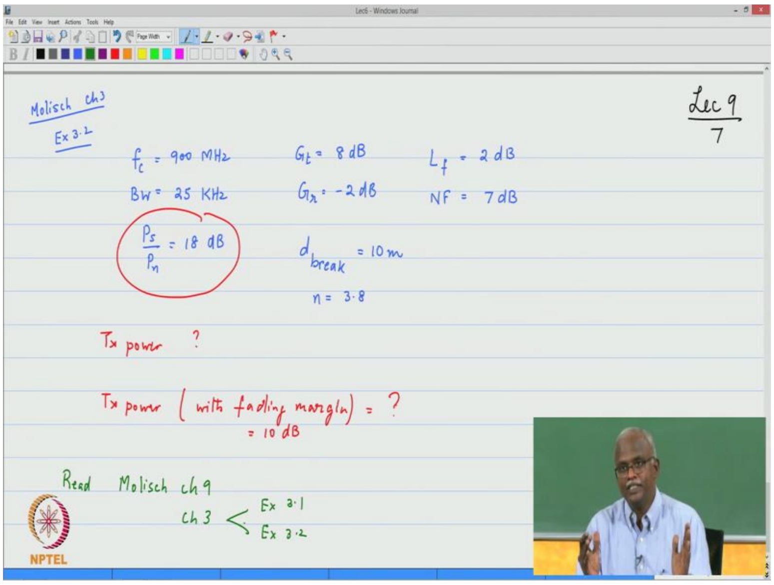

So, this is also taken from Molisch chapter 3 this is example 3.2 and by the way the previous example that we had looked at was example 3.1 in Molisch the second one is 3.2 is the expression that we have.

So, the problem that statement are that I have a signal that is at a carrier frequency of 900 megahertz, the bandwidth of the signal is 25 kilohertz and we are given that there is a transmit gain of 8 dB and a receive gain of minus 2 d B, and there are several losses in the system we call that as the losses in the system and that is of the order of 2 d B, the noise figure of my receiver is 7 dB and what we would like to achieve is a P s by P n of 18 dB we would like to achieve a (Refer Time: 52:56) signal to noise ratio and we are told that we can take the break d break as a distance of 10 meters with a path loss exponent of 3.8..

Now, the question that we would like to answer which is a very important question is what is the transmit power under these assumptions that we have expressed or give explained in this example what will be the transmit power that will ensure that we achieve a P s by P n of 18 dB with these conditions that are mentioned here. Now to make it a little bit more realistic we would also like to look at what is the transmitted power that will achieve this with a margin with a fading margin of fading margin of 10 dB.

As we discussed the role of a fading margin is to make your systems more robust. So, when we have a fading margin incorporated into the design, we would have to transmit with higher power. So, we want to what would be this with a fading margin of 10 dB. So, again these are 2 questions that we would like to answer. So, what I would like to request you is do read Molisch chapter 9 to understand about antennas and chapter 3 were examples 3.1 examples 3 point worked examples 3.1 and examples 3.2 to understand link budgets system design fading margin and how all of these will work together to help us understand and build robust wireless systems.

Thank you very much.