Satellite Communication Systems
Prof. Kalyan Kumar Bandyopadhyay
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 11
Link Budget-1

Good morning. Now, we have seen different topics. One was an orbit and its dynamics and then, we went to briefly the space segment of different subsystems in the space segment and environment in which it operates. We will slowly go into deeper into the subject. Now, today onwards for few lectures, we will discuss one of the very important aspects of this wireless communication is link budget.

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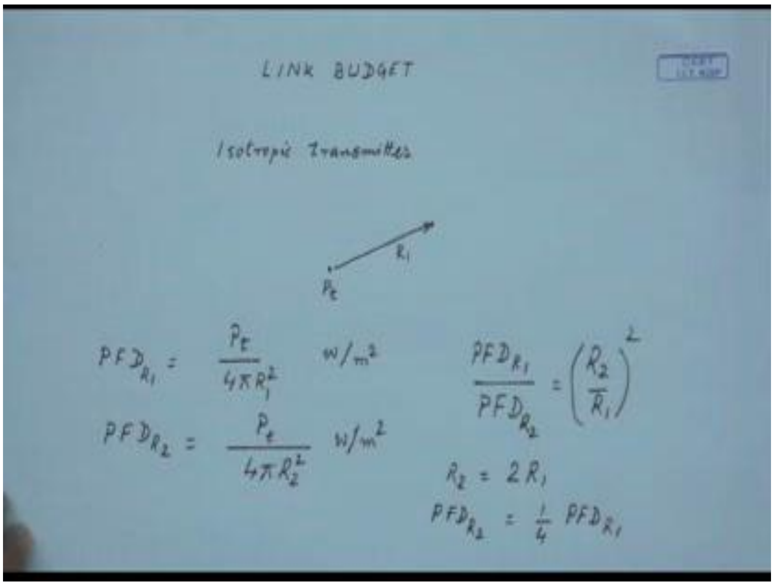

So, this is link budget. That means, from the transmit side to the receive side, the wireless link which is there how much power is required and how much will be the noise in it. So, first we will consider the power part and then, will go into the noise part. Let us start that there is a transmitter which is an isotropic transmitter. This isotropic transmitter means that there is a point source and from which the power is radiated and it radiates spherically all over. So, that power source let us call it as P, T is the power in words it is transmitting and it is going spherically all around.

So, power transmitter is PT and the power at a distance let us say R1, distance the power which will come here can be estimated as power transmitted by it as a sphere. So, the surface of the sphere that is 4 pi R square or if it is R1, then it is R1 square. This is called power flux density and its unit is watt per meter square. Now, let us look at this. The power is getting reduced by as I increase the distance, it reduce by square of the distance in more much implication of that. It is PFD at R1 now if we try to see the power flux density at R2 it will be P t by 4 pi R2 square watt per meter square now if we take the ratio of this two try to find out how much power is changed from R1 to R2 assuming r2 is as a larger distance. So, PFD at R1 by PFD at R2 will be R2 by R1 whole square. That means, if let us say R2 is two times R1 than PFD of at R2 is one-fourth of PFD at R1; it is square of the ratio of the distance. So, it is getting spread with that distance of the path.

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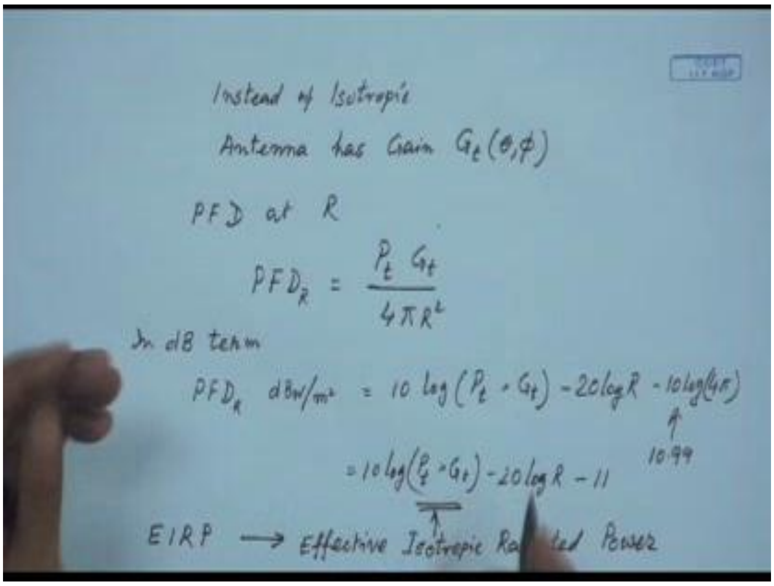

Now, let us look at it in more detail, that is let us see that instead of isotropic we have a focused radiation. So, instead of isotropic we have an antenna instead of radiating in all direction uniformly. Antenna has gain let us call it transmit antenna. So, let us call it G t. We have talked about the gain of the antenna, how it is defined that is the input power which is coming, how much it is focused in G theta phi direction. In theta phi direction g goes in theta phi direction and in with R will be reducing the power. So, PFD that is power flux density at R will be PFD; at R will be that is P t which is the power which is radiating into G t by 4 pi R square. Now, this G t we have an earlier said that is normally in theta phi direction, but in general people take as G t is the maximum that is in the bore side it is taken, but this is a standard general formula and G t at theta phi direction if we see how much power is reaching there, we can find out by putting that G t value multiplied by P t by 4 pi R square.

So, this if we put into dB, there is a reason for putting into dB term because we will be dealing with very large numbers. We have seen already that R from ground to satellite or satellite to ground the range distance sometimes it may go to 36000 kilometre, 40000 kilometre of that order and square of that. So, these are large number. So, dealing with large number, it is preferred to work in dB. So, in dB terms that PFD at R which is in its dBw per meter square, we are transmitting in watts dBw per meter square that will be 10 log of P t that is put into G t minus 20 log of R minus 10 log of 4 pi. Now, this value 10 log of 4 pi is roughly of the order of 10.99. We can take it as 11. So, it can be simplified as 10 log of P t into G t minus 20 log of R minus 11. These are all in dB terms.

Now, you can observe that I did not do it as 10 log P t plus 10 log G t. Instead I have put P t into G t. So, there is a reason for it that earlier we are assumed that G t is same in all direction. Now, we are putting G t maximum in one direction slowly reducing in theta phi. So, multiplication of these two is a term which is called effective isotropic radiated power. In short it is called EIRP. We will use this term very frequently. So, is called EIRP that is effective isotropic radiated isotropic radiator. Now, we have made some focus in that is G t. So, its effective isotropic radiated power is P t into G t. Let us go a little more detail of that.

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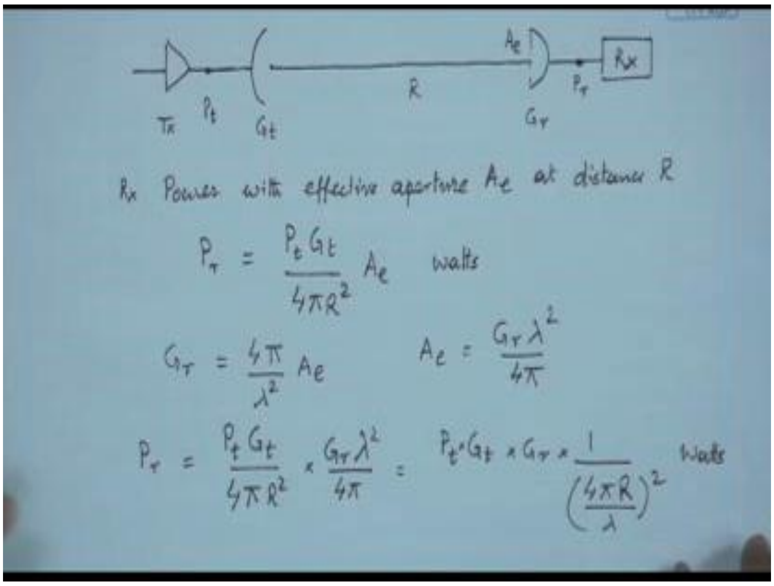

We have now seen that a transmitter which has an amplifier power amplifier whose this is a transmitter whose power output is P t and it is put into an antenna will use parabolic reflector antenna because a larger gain is required to focus the energy or the power. So, this antenna has a gain G t and then, from the aperture of this antenna at a distance R, we have a receive antenna which has again G r and which has aperture whose effective aperture let us call a e effective aperture through which it captures the power and then, receive power will be P r here which will be given to the receiver. So, the input power to the receiver is P r. So, receive power with effective aperture of e at distance R can be stated as P r is P t into G t by 4 pi R square. This is watt per meter square and effective aperture of that millimetre square will capture this. So, this will be in watts.

Now, that is the amount if I go on increasing the effective aperture, I will capture more power if you at antenna aperture is smaller will capture less power. So, therefore, antenna aperture is very important issue. Now, this is an effective aperture and of course, it is related to the gain of the antenna. So, we have seen earlier that gain of the antenna in case of, in this case receive antenna is 4 pi by lambda square into effective aperture. That means, effective aperture is equal to receive antenna gain into lambda square by 4 pi. So, this expression of an effective aperture if we put it here, then the receive power will come in terms of transmit power.

Transmit antenna gain the distance, the receive antenna gain and of course, at the frequency of the wavelength at which it is being transmitted. So, it can be expressed now like P t into G t by 4 pi R square into effective aperture which is G r lambda square by 4 pi. This expression can be rewritten by readjusting that is P t into G t into G r into i adjust now and make it 1 by 4 pi R by lambda whole square. It was a two 4 pi's are there. So, 4 pi square and R square is the lambda square. So, 4 pi R by lambda whole square, now this is in watts. Remember all these numbers are in ratio is not in dB right now. So, let us rewrite again.

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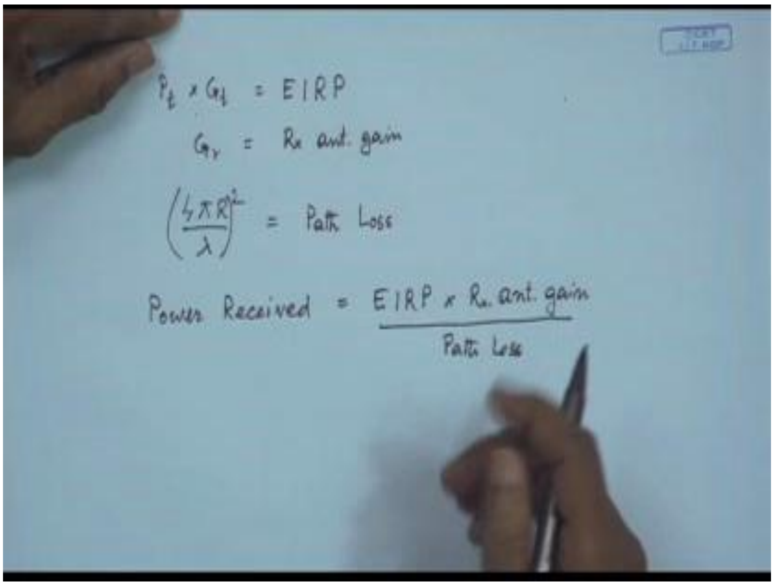

So, we have seen that P t into G t we have defined, then have a term called effective isotropic radiated power and G r is the receive antenna gain and now we have seen this power is reduced by a factor 4 pi R by lambda square. Since it is reduced by this factor is 1 by this thing. So, this one could be treated as a loss. So, let us call it 4 pi R square 4 pi R by lambda whole square. We term it as a loss and since it is depended on the path length R at a distance R, so is path length we call it path loss. This term path loss some people use has a free space loss, but we will see that it is not always free space through atmosphere also it travels. So, it is better to define it as a path loss because it depends on the path length.

So, in other words if I write it will be power received is equal to EIRP into receive antenna gain divided by path loss, now you just see this is lot of ideal conditions we have taken that is antenna gain at the transmitter and receivers we have taken the maximum value. Of course, G theta value theta phi value also could be taken we are taken here as a maximum value and the loss due to the distance and dependent on the frequency of operation, the path loss is calculated and of course, you can see here that if the frequency increases that is when the wavelength is smaller and smaller the path loss will increase.

We have seen earlier for satellite communication bands which are given commonly used is c band that is at 4 to 6 gigahertz range Ku band which is 10 to 12 gigahertz range or K a band which is 20-30 gigahertz range. So, you can see as we go from c band to K u band to K a band our frequency is increasing as the frequency is increasing the lambda value reduces. So, therefore the path loss at c band and will be much less compared to K u band which is also less compared to K a band. So, as you go up in the higher band, the loss is more. Remember this that we are going to face a problem that when you go for a higher band of operation, you know loss will be more. If you recollect our table of ITU frequency allocation or very roughly in the last period also we have shown that is at c band normally 500 to 700 megahertz is available as a band width for space communication in K u band. It is roughly about 1 gigahertz is available. So, band width is more at higher frequency and allotment at K a band is almost 2 gigahertz-2.5 gigahertz available.

So, from the ITU point of view or availability of spectrum point of view, it is preferred to go to higher band, so that we can increase the capacity. More users can come and larger band width is available, but there is a problem that your path loss will be more. Therefore, I mean assuming the R is same that is your working at geostationary satellite, R is same. Let us assume in that case path loss at higher spectrum will be more. So, therefore the antenna gain has to be increased. We will see all those things in detail calculation when we do. Now, one thing we should also see that it is quite ideal condition. There may be other losses and when the loss is come, they will come in the denominator, so that power received will be lower and lower. Let us see what are the possible other losses that can come. One of course is we have assumed that antenna is pointed, but antenna may not be properly aligned. So, it is called antenna de pointing loss.

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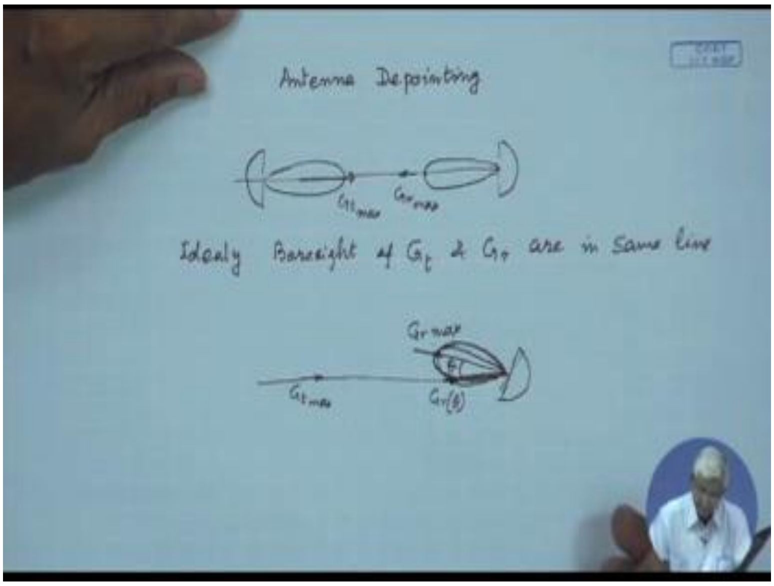

Let us see pictorially if you try to draw this is the line, this is the transmit antenna. So, its beam is like this and in this line of sight operation, the receive antenna is there and its beam is supposed to be like this. The beam width will depend on aperture size of that. So, normally it is this is the G t max and this is the G r max. That means, ideally the bore sight of G t and G r, are in same line. This is ideal condition, but you know practical purpose many times it may not be at the same line. So, let us look at it how it will look like that. Let us us say this is the line on which the G t max is coming and your receive antenna is miss pointed or de pointed with. This is the parabola, this is the aperture and its beam is like this. Let us say that means this is G r max and this point is the G r theta and this angle is theta.

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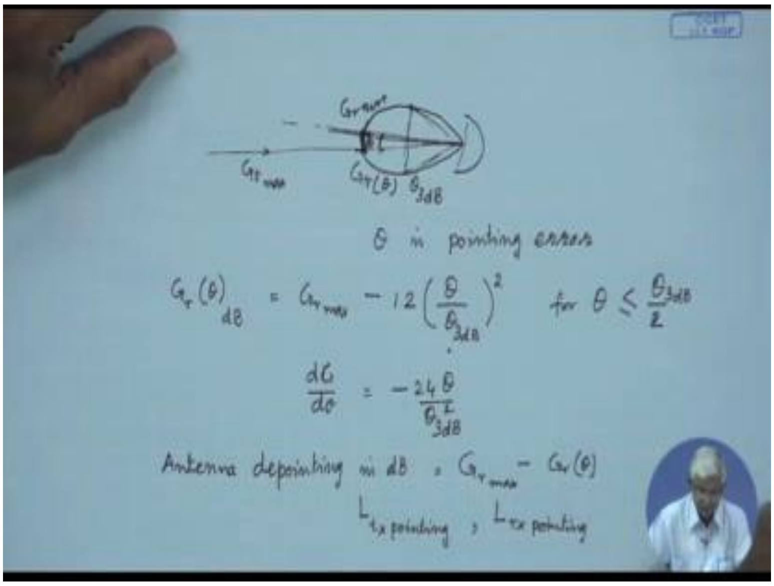

Let us draw it fresh. This is the line and you have an antenna which is slightly de pointed not getting the maximum that is called this one is G r max and this is the G r theta and this angle is theta by theta angle. It is de pointed, this is the receive antenna by theta angle, it is de pointed and this is G t max. So, it is reduced from pictures which is G r max and let us assume that half power point for this is here. So, this angle is theta 3 dB. Now, normally this parabolic antenna has a typical pattern here the maximum. So, that can be modelled and error from the maximum by theta is theta is the pointing error. In this case, it gets these models says that G r theta value in dB is G r max value minus 12 times theta by theta 3 dB square.

Now, this part is valid for theta is less than equal to theta 3 dB by 2 for small angle. For small angle it is larger than theta 3 dB may not be this is just a model. I mean all antennas are not ideally like this. They may have different shapes and etcetera, but just for thumb rule. So, the gradient says d g by d theta differentiating that you can get a minus 24 theta by theta 3 dB square. Now, this antenna pointing loss then are antenna de pointing whatever you call in dB is G r max minus G r theta. This value this is the reduction from here to here. This is from here to here and this is the reduction. So, this can be term, let us term it as l for the transmitter side. It may happen for the receive side, it may happen. So, for the transmitter side will call one transmitter pointing or we can call it one receiver pointing. These are pointing error or de pointing or pointing loss, where we space this is one type of loss we have discussed. So, let us see is there any other type of loss.

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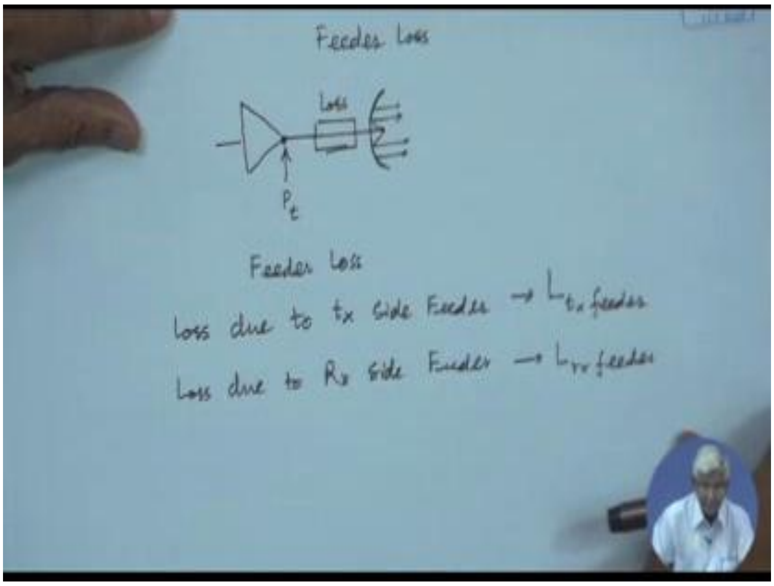

There is another thing that is we have assumed that the transmitter amplifier output at this point is P t and then, there is an antenna and the focus of the antenna, the power is going and it is radiating this is the reflector. Now, from this power amplifier output to this focus point, it will be connected through cable waveguide. There may be bands and there may be adapters. So, all these things can introduce some loss, so that can be grouped as a loss. It is called feeder loss.

So, loss due to transmit side feeder we are using the term feeder that is it is feeding the power from here. That is power amplifier to the antenna. So, antenna feeder loss transmit side feeder we can term it as one transmit side feeder and loss due to receive side feeder is loss r x feeder. So, this is we can call feeder loss. There can be other type of losses since the time is almost up.

So, we will continue the discussion with the other type of losses in the next class.