Millimeter Wave Technology
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Module 8
Lecture No 36
Millimeter Wave Systems

So last day I have introduced concept of noise, noise temperature and what is noise figure. So today we will study these parameters in details and we will see what are the important of these parameters when we go for any millimetre wave systems design. And after that we will calculate the SNR for any given millimetre wave system and as an example I will show you one application example Passive imaging millimetre wave system, which is already in use and finally I will be introducing some different popular architectures, transceiver architecture is used at millimetre wave frequencies. So let us start with the noise, its concept from where it comes and what is the effect at millimetre wave frequencies.

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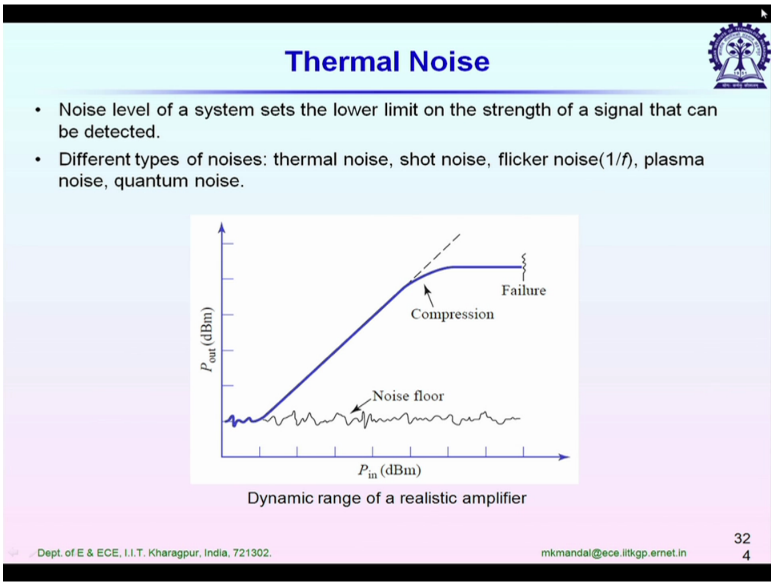

So for any given system, noise level it sets the lower limit on the strength of a signal that can be detected. So now the sources of noise it can be different, it can be thermal noise, shot nice, flicker noise, plasma noise, quantum noise, et cetera. Among these, thermal noise it plays the most important role and its contribution is highest among all these different noise sources. So why thermal noise happens, this is due to random fluctuations of dielectric molecules and inside metals also due to random motion of electrons due to thermal agitations. We also have shot noise, typically in solid-state devices and in tube based devices due to random re-combination of electron-holes and random motion of charge carriers. Then we have flicker noise, this noise it varies inversely with frequency, at millimetre wave frequency the effect of flicker noise is negligibly small.

Then we have plasma noise, let us say we are sending some millimetre wave signal through Ionosphere or some charged medium so in that case this charge medium this charged particle they will all so vibrate due to thermal agitation and due to that we have some contribution of noise. And then quantum noise, this is due to the quantised energy level of charge carriers, but again contribution of quantum noise is negligibly small. So as I said that the contribution of thermal noise is highest among these, so mainly in this class we are going to concentrate on the effect of thermal noise, it is also known as the Nyquist noise or junction noise, some other names. Now let us say we have a millimetre wave component, it can be an amplifier also, now for any amplifier the gain will be specified, you can consider not just millimetre wave amplifier, it can be a very basic common emitter amplifier.

So in common emitter amplifier test if you remember that what we did in our UG first year class that the signal handling capacity of a C amplifier, so in that case the application factor is given, then what we do we change the input power level and measure the corresponding output power. So this amplifier or any other to port device we always assume it, it will work as a linear device, but what we see for C amplifier, if we keep on increasing the input power level at some point it starts to deviate from that linear characteristics and the output waveform it is distorted, it is not an exact replica of the input waveform and recall that it enters the non-linear region, so if I plot then P out versus P in for the first part it will be a straight line and then it will deviate from the straight line.

So if you look at this graph, you see the first part it looks like a straight line, here we are showing P out in dBm versus P in again in dBm, so if we keep on increasing the input power level at some point the device it saturates. So it determines highest input power that can be applied to this particular component or it can be also any instrument. And again after that if we keep on increasing the input power level, so at some point the component will it might burn the component, we call that point the failure point. Now if I go to lower power level, you see the lowest power level that can be sensed by this component or if it is an instrument by the instrument, it is given by the Noise floor. So, this noise it comes due to the various reasons we discussed earlier and it generates, it is generated inside the components or instrument itself and then would be some noise which is also coming from outside.

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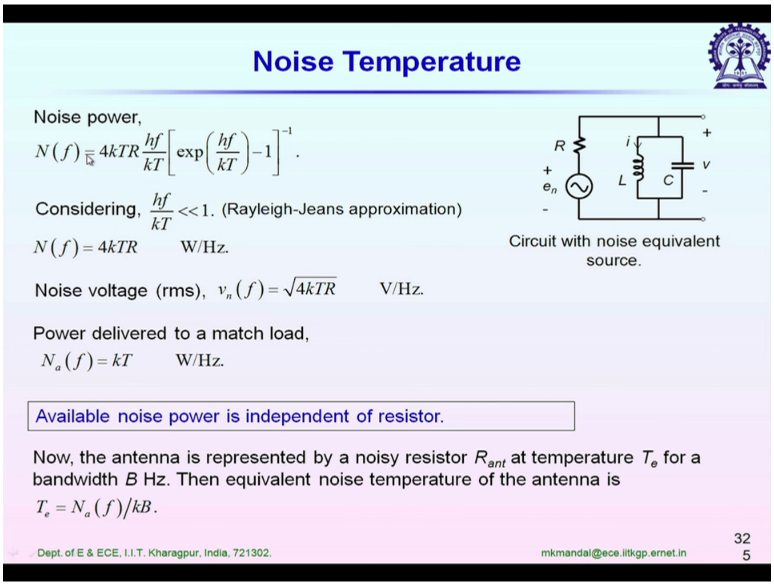

So we will discuss all these points on how to model this internal and external noise for any millimetre wave system. So last day we have seen that in general noise power from any register which is at a temperature T, it can be given by this expression 4 k T Rm h f by k T divided by exponential h f by k T - 1. Now if we consider a low frequency high temperature case, so that means h f by k T much less than 1, this condition is also called Rayleigh Jeans approximation so in that case E to the power X we can terminate the exponential series by its first 2 terms, so it is 1 + X that means 1 + h f by k T, so we have finally then N (f) = 4 k T R. So this is the noise power available noise power generated by the resistor, the corresponding noise voltage RMS value is given by square root of this 4 k T R volt per hertz, we are not considering any bandwidth.

So if we consider noise power over some given bandwidth B, then we have to introduce a bandwidth term here and it will become square root of 4 k T R into B. Now also we have seen last day that whatever power is being generated by the resistor, it is not available to system. You recall maximum power transfer theorem, so maximum power that can be extracted from this resistor, so that is given by maximum power transfer theorem when load is meshed to the source resistor. Or if we connect another resistor of the same value R and in that case if we calculate the noise power that is being absorbed in that load second resistor, it becomes independent of resistor. So the value is given by N a, which is of course a function of frequency, this is equal to k into T, k is the Boltzmann’s constant.

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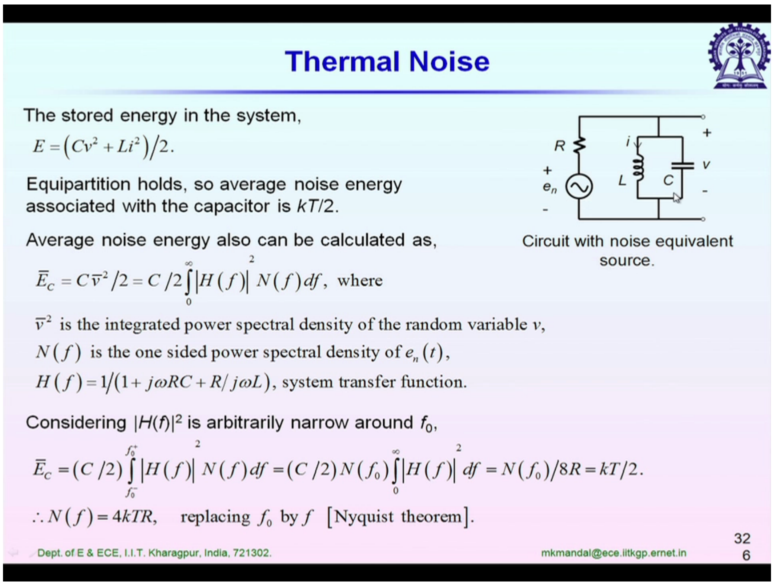

So important conclusion is that then available noise power is independent of resistor and noise power we can also express in terms of some equivalent temperature and in that case the equivalent noise temperature T e for a bandwidth B hertz, we can express T e = N a by k B. We have also seen that if a tank circuit resonates, L-C resonator is connected to this noisy resistor, then the total noise power k T is divided into 2 parts and half is stored in H inductor and capacitor that also we proved.

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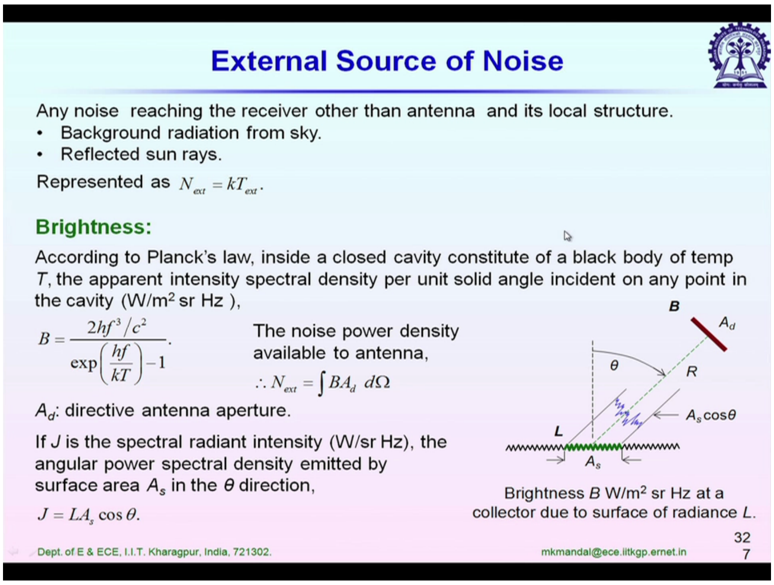

Next we will discuss about the external noise sources, so external noise sources it can be many things. So let us say we are using any wireless millimetre wave system, it can be also one radio meter, so now you see external we have Sun, we have stars and galaxies they are constantly illuminating Earth surface. So some of this power will be attenuated by the atmosphere and then it will be re-radiated by the atmosphere, we call it Down-welling radiation from atmosphere. And by this down welling radiation from atmosphere, earth surface is constantly being illuminated. So if we point any antenna towards earth, then all this re-radiated power from earth surface, it will be collected by antenna and it will work as an external source of noise.

We quantise this external reflection from earth surface by its brightness, I will introduce the parameter and we will discuss its effects in details later. We also have some external sources, some other wireless links maybe, we also have external let us say Bluetooth device, Wi-Fi device, so many wireless systems already are in use, it can be mobile base station, it also radiates their harmonics and it can be at millimetre wave frequencies. So there are many sources, but here mainly we are going to concentrate what is the effect of this downwelling radiation or brightness from the earth surface, so let us study brightness in details then.

According to Plank's law, inside a closed cavity constitute of a black body of temperature T, the apparent intensity spectral density per unit solid angle incident on any point in the cavity, which can be given by watt per meter square per steradian hertz is given by brightness B, this is equal to twice h f cube by c square divided by that exponential function. Now what is black body? Black for black body, it is called the perfect absorber or perfect ammeter at the same time, so whatever it will absorb the whole power it also will re-radiate. Or absorption coefficient is 1, similarly its MCVT that is also 1.

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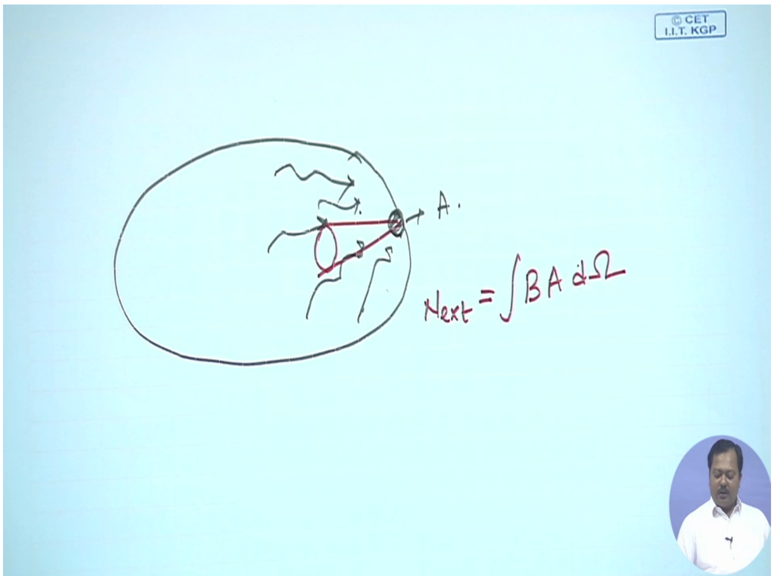

Now let us consider a closed surface, it is made of black body and inside it is radiating due to its temperature. And let us say what radiation is falling on a surface here of area let us say A, we want to calculate. Now then radiation is coming from all different angle over this and now we are defining one unit solid angle and let us say we are calculating what is radiation coming through this unit solid angle and then we integrate it over the incident area A. So then the brightness, you see it represents the brightness if you consider it per unit area and per-unit bandwidth unit hertz, so you look at the unit of brightness; it is watt per meter square per steradian hertz. Now if I want to calculate the overall radiation received by this area A, in that case simply we have to integrate N external we can say, we have to integrate it B A d omega over all the available solid angle, so we can also use similar concept for any antenna.

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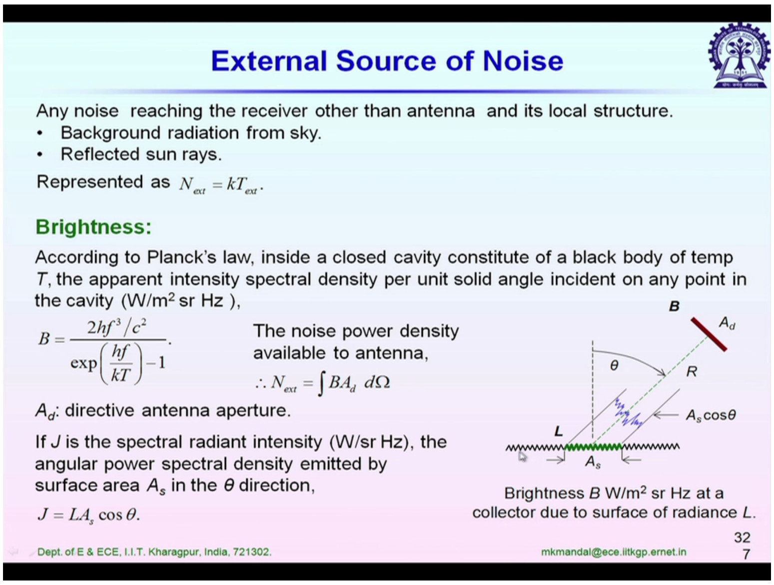

So let us go back here, so we are representing any earth surface let us say here and considering radiation coming from an area A s. And this radiation now it is in arbitrary direction and some part will impinge on the antenna, antenna area is given by A d. And this antenna it makes an angles Theta with (())(13:51) of this earth surface A s, so obviously the power scattered power radiated power whatever received by this antenna, it depends on this angle Theta, it depends on the polarisation of antenna and also the surface roughness of this surface and the dielectric constituents of this earth surface, so it depends on so many factors.

Now let us say we are defining a parameter J, which represents the spectral radiant intensity so watt per steradian hertz, then the angular power spectral density emitted by surface area A s, in the direction theta, so what we have to do then J that is equal to L A s Cos Theta, where L it is called the radiance, so we are considering radiance is simply the brightness per unit solid angle per unit area. So what we are doing here, then we are we have to multiply the L by this area term to obtain the total radiation received by the antenna. So for that we cannot take simply A s because the antenna it is making an angle Theta, so we are taking projection of s and it becomes A s Cos Theta, so then the spectral radiant intensity at the antenna point it is equal to L A s Cos Theta, so this is for unit solid angle.

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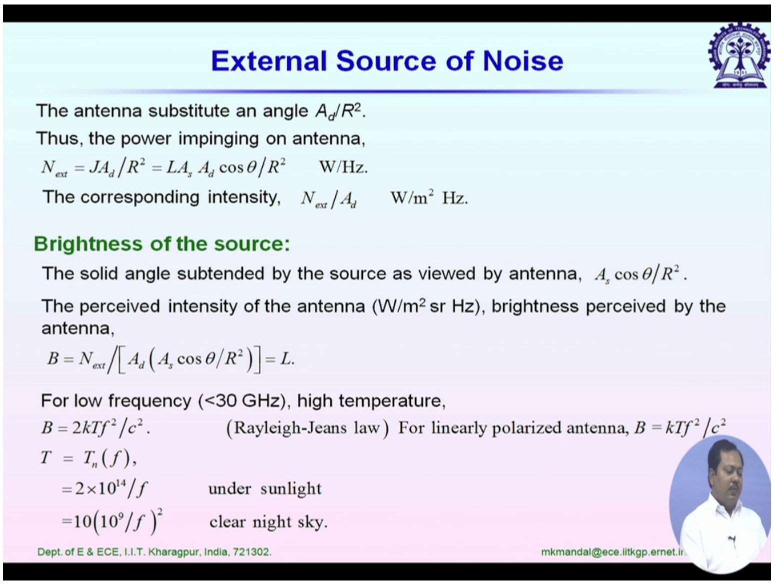

Now the antenna, it substitutes an angle A d by R square. If we are assume that R is much more than A d, then the solid angle substitute by the antenna it is given by A d by R square. Then the total power impinging on antenna, which is N external so for that we have J per unit solid angle, we have to multiply it by the total solid angle given by the antenna, so this is J A d by R square. Now if we put the value of J, which we have seen L A s Cos Theta, it becomes L A s A d Cos theta by R square watt per hertz, so this is the total power received by antenna from the surface area of A s due to its radiance L. Now we can show that the brightness of the source as seen by antenna it is nothing but L, how?

We are just considering the opposite scenario, in this case we see that the surface area A s what solid angle it makes to antenna and then we calculate the brightness for that. So solid angle subtended by the source as viewed by antenna, this is then the area divided by R square but we have to take the projection so it is A s Cos Theta by R square. Then the perceived intensity of the antenna or brightness perceived by the antenna B, this is equal to N external divided by A d divided by A s Cos Theta by R square, so total power we know intensity we know and that we have to divide by the angle, so that then it will give will have the value per unit solid angle. So if I put the value of N external from previous equation so it becomes simply L, so we see that whatever may be the angle whatever may be the A s or A d, brightness perceived by antenna it simply becomes L.

Now brightness, it depends on this surface roughness of earth, it also depends on the dielectric constituents of earth and obviously it depends on frequency under Sun it will have some value, under cold sky at night it will have some different value, so roughly if we consider low frequency below 30 gigahertz and high-temperature, B this is twice k T f square by c square and this is we are considering whatever power it is radiating we can receive all of this, but if the antenna is linearly polarised, we cannot receive all of this power, only we will be receiving half of this. So in that case for linearly polarised antenna then B = k T f square by c and the corresponding T it obviously function of frequency, so approximately this is 2 into 10 to the power 14 by f under light and 10 into 10 to the power 9 by f whole square under clear night sky, so it varies with the condition.

So we have seen the effects of external sources typically the radiation from earth surface. Now let us consider the noise contribution of the components of any receiver chain and from that let us call calculate the overall signal to noise ratio for a given receiver. So let us start with a simple 2- port network, so whenever any power is incident on that 2-port network, let us say the incident power is P s, then at the output side we have the gain of the 2 port component multiplied by the input power that will be the available output power, but at the same time we also have some noise with the incident power P s. And in addition to that noise the component itself will add some noise, so then the at output point if we calculate signal to noise ratio, it will be lower than the signal to noise ratio at the input side.

Why, because the component is also adding some noise, so overall noise contribution then it will increase at the output side. So let us first characterise one 2 port component simply, when we are not considering any external noise, so after that we will add some external noise from left-hand side and we will calculate the overall noise contribution of the 2 port device, so let us start with a simple 2 port network.

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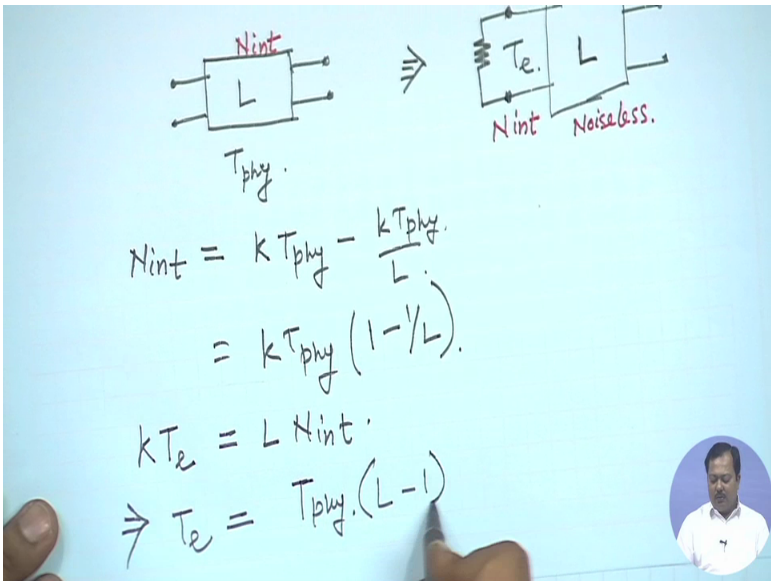

Let us say this 2 port network temperature it is in thermal equilibrium and the physical temperature is given by T phy and the loss factor of this 2 port network if L. So if we want to represent in terms of gain, then simply L equal to 1 by G. Now this 2 port network itself it will produce some noise, so in that means we can represent this 2 port network by an equivalent resistor at some equivalent temperature T e, it will give the equivalent noise temperature and which we will place on left-hand side of this 2 port network. So for the first case we have noise generated internally and in the second case this noise we are representing by effective temperature T e followed by a noiseless 2 port network.

So then N internal we can write down, this is k into T if I consider per-unit hertz then it is simply k into T, so this is k T physical - k T physical divided by L or we can write down this is k T physical into 1 - 1 by L, where L it represents the loss ratio. So if I want to represent in terms of gain then L will be simply 1 by G, then the corresponding equivalent input noise temperature we want to calculate, so then corresponding noise temperature if this is T e, in that case k T e, this is equal to L into N internal if I look at this second network. So T e, it is now providing me the N internal then we have a noiseless 2 port network for again its loss is given by L. So we can write down then T e this is equal to T physical into L - 1, so this is one important relationship.

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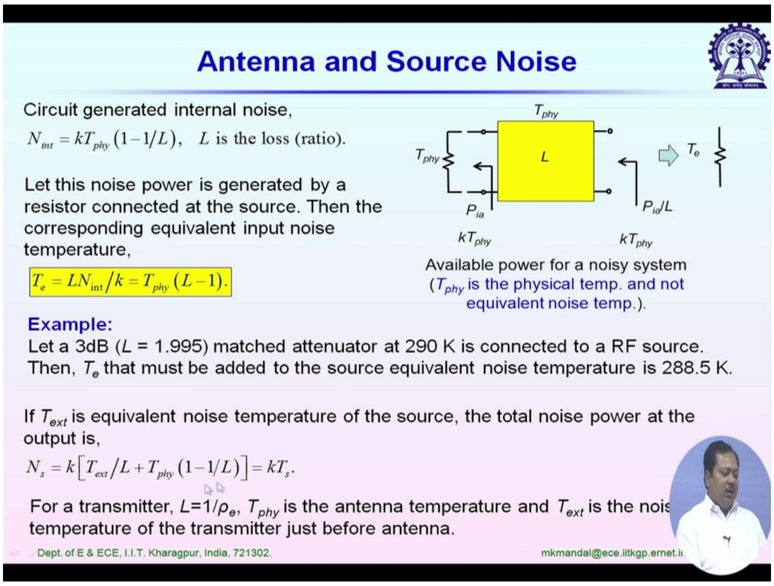

So if the physical temperature is given, let us at the physical temperature is 300 Kelvin so then if I know the loss value then we can calculate what should be the effective noise temperature T e. Let us take one example, let us say we have one attenuator 3dB attenuator it is meshed attenuator at 290 Kelvin and it is connected to a RF source. Then the T e that must be added to the source equivalent noise temperature is 288.5. So how we are getting, so 3 dB this is we are considering power loss so then in fraction we can write down how to calculate the value in fraction, so it will be then simply 10 to the power 0.3. And you put the value of L here, then T e that is equal to T physical, which is 290 multiplied by L - 1, so it is 0.995 and the value is 288.5 Kelvin. Okay, so now we will take a break after that we will see let us say we have also some external noise, which is incident from left-hand side on this 2 port component okay, thank you.