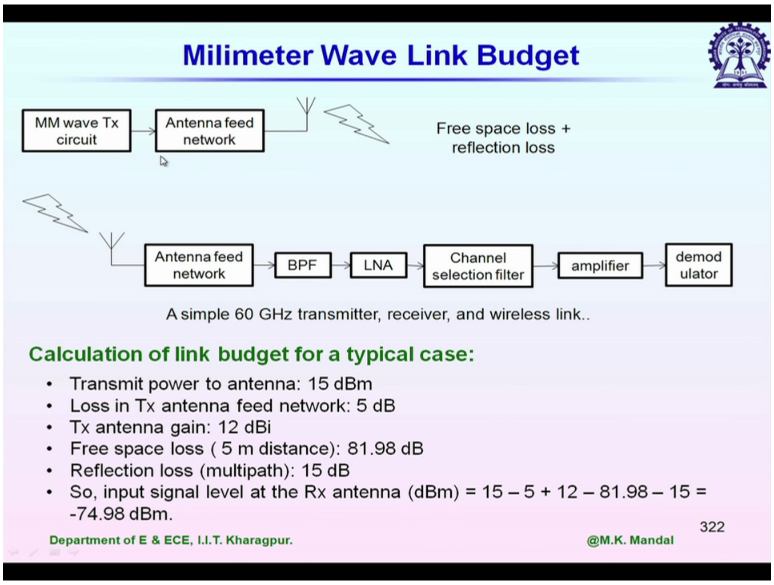
Millimeter Wave Technology
Professor Mrinal Kanti Mandal
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology Kharagpur
Module 7
Lecture No 35
Passive Components (Contd)

(Refer Slide Time: 0:29)

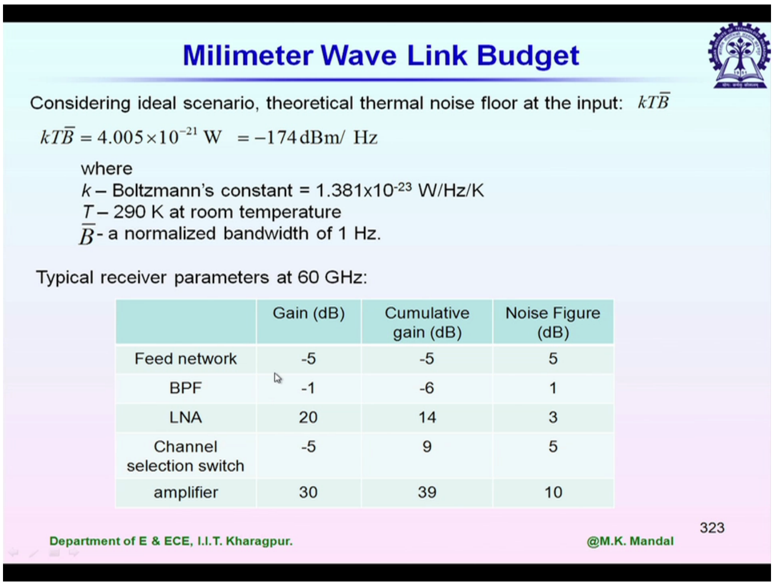


So let us take one numerical example, we will be calculating link budget for a given system for a millimetre wave system. We are considering a simplified transmitter and receiver circuit, where the transmitter is shown here we have a millimetre wave source followed by one antenna and in between we have antenna feed network, antenna feed network is lossy, it can attenuate more than 50 percent power. Next, at the receiver side we have to receive antenna then antenna feed network followed by band pass filter, we typically use a band pass filter just after the antenna to minimise the thermal noise contribution as well as to minimise any undesired interference from other sources. And immediately after that we use a low noise amplifier for which noise figure is very small. We will discuss later that why we need to use a LNA as soon as possible just after antenna.

Because in chain of any given receiver, the first component determines the overall noise figure of this receiver, so if I use a smaller value of noise figure for the first component then the overall noise figure of the receiver it will decrease. Next is channel selection filter, it can be a switch also followed by high gain amplifier and then the demodulator. So some typical values are given for a 60 gigahertz system, transmit power to antenna is 15 dBm, loss in transmit antenna feed network is 5 dB, it is quite high, 3 dB represents 50 percent loss even it is more than that. Transmit antenna gain : 12 dBi, free space loss at 5 meter considering N = 81.98 dB and reflection loss due to multipath, so due to multipath we are subtracting some power which is given by 15 dB.

So input signal level at the receive antenna in dBm we can calculate, so the positive contribution is due to transmit power and the gain of transmit antenna so 15 - 5 + 12 - path loss - reflection loss, it comes approximately - 75 dBm, so this is the power signal level at receive antenna.

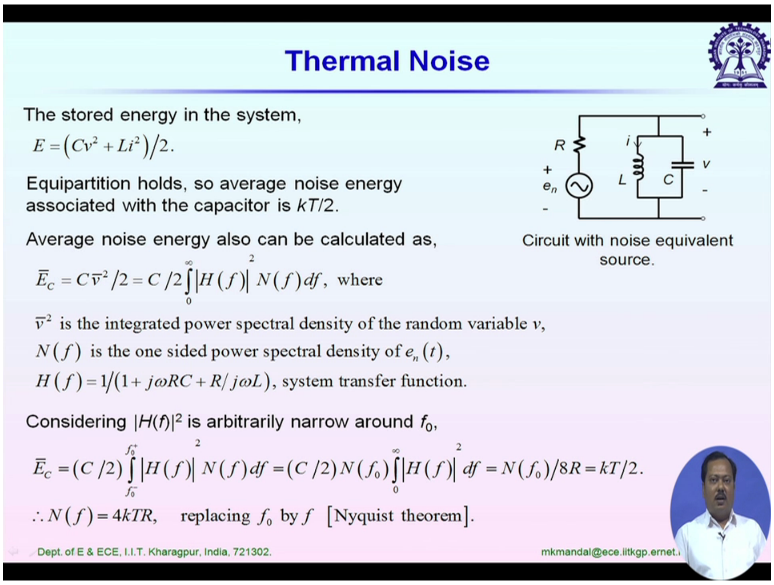
(Refer Slide Time: 3:23)



Now at the receive side let us say these are some typical values given here. Feed network loss 5 dB, so that means gain is - 5 dB we can say or cumulative again just after antenna due to feed network - 5 and for any passive components for which gain is less than one or lossy network, noise figure again noise figure is the ratio of SNR at the input to SNR at the output, it is equal to simply gain of the device. So if any device provides 5dB insertion loss, its noise figure will be 5 dB. It is followed by a BPF for which the loss is 1 dB, cumulative gain - 6 dB, next we have a LNA then LNA again is given 20 dB and cumulative gain then 5 + 6 - 20 it comes 14 dB. Channel selection switch, it has loss 5 dB and then it is followed by one amplifier and cumulative gain is 39 dB.

But when we are considering total gain of this chain, we did not calculate the total noise contribution due to this chain and also what happens for the noise what is coming with the signal? Some noise again will be collected by the receive antenna due to the radiation blackbody radiation, so we did not consider all those effects because we do not know till now how to calculate that, so after this we will concentrate on that topic how to calculate the overall noise contribution and hence overall SNR for the receiver.

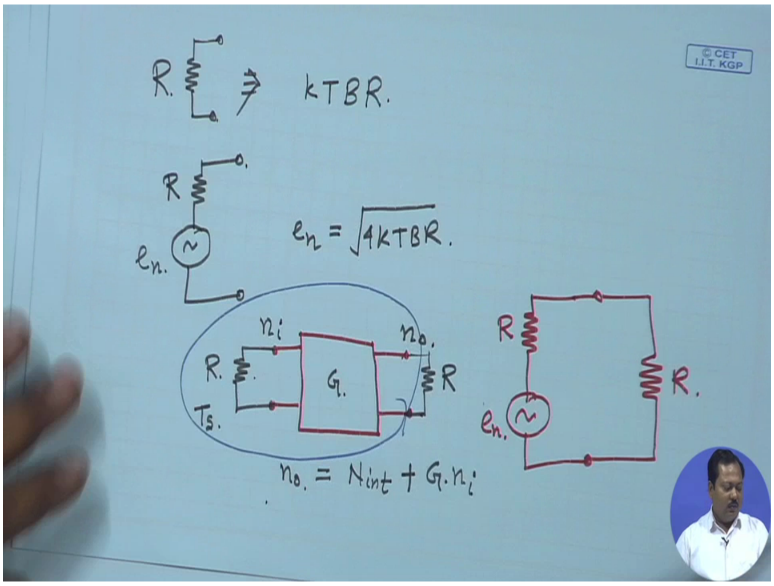
(Refer Slide Time: 5:35)



So let us start the next topic, there are many different sources of noise, thermal noise, flicker noise, short noise, 1 by f noise, but here mainly we are going to consider the effect of hormone noise. So it happens because of random vibration of molecule, this is due to thermal agitation and as the temperature increases, then their thermal agitation increases and noise contribution also increases. And we can model a thermal noise by all the frequency components by a random variable, which has all the frequency components so that is why sometimes we call it white noise which has all the frequency components. Now since our receiver it will have a finite bandwidth, it cannot pick up all the thermal noise components; it will pick up the components whatever we have inside bandwidth.

So for now we will consider ideal band pass type response, so the bandwidth whatever the receiver has we will represent it by a rectangular window function and below or above that frequency range, the contribution of thermal noise is simply 0, but actual noise bandwidth is different that we will discuss later. So then from a resistor if we have a resistance R, which is let us say at temperature t, the noise power generated by the resistor we can write-down that is equal to k T into B R, where B is that bandwidth of that rectangular window function.

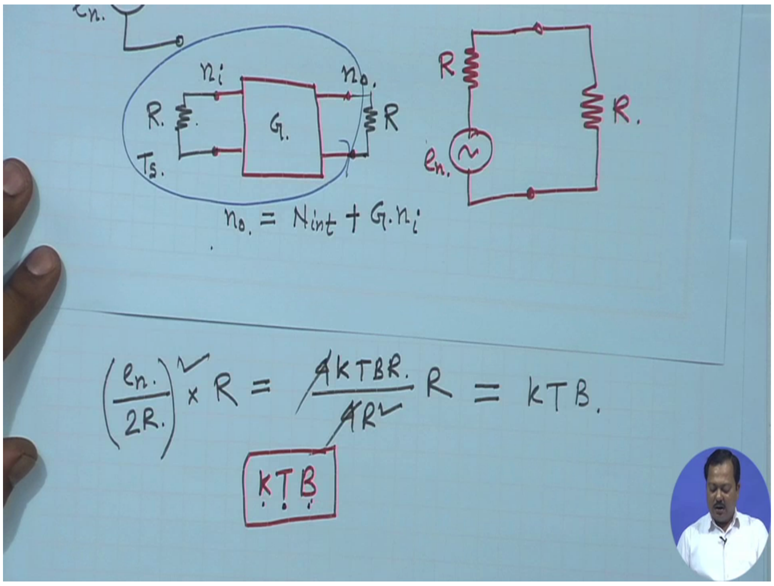
(Refer Slide Time: 8:03)



So in general then let us represent one resistor R then the noise power this is given by k T, where T is the temperature of the resistor into B into R. Then if we represent this noise by a noiseless ideal resistor in series with a noise source let us say the voltage RMS value it is e n in that case e n this is equal to it is 4 k T B R. It can be shown that the noise contribution it depends only on the temperature of the resistor, not the resistance value okay, let us consider one scenario. If we have any component, it can be a passive component, it can be an active component, now we are using it in the system, let us say one source is connected to this component, source resistance is given by R and it is meshed to a load that is also given by R. We are considering a meshed scenario, so this input size is meshed to resistance R and output side of this two port component that is also meshed to R and this resistor it is at a temperature T s.

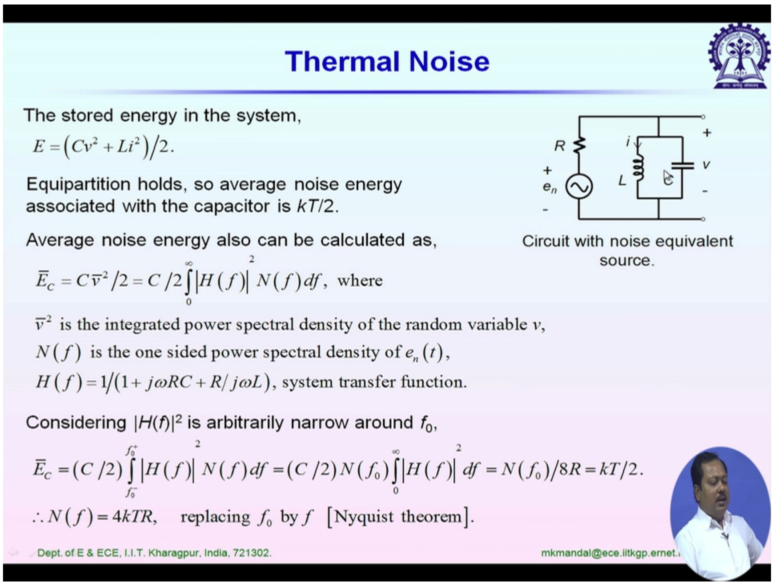
So now whatever noise generated by the resistor at left-hand side, it will be the input to this 2 port device and depending on gain or loss, it will be attenuated or it will be amplified that noise contribution from left-hand side and it will be delivered to right-hand side. So in addition to that, this 2 port component itself it will produce some noise so total noise contribution at the output side n 0 this is equal to let us say gain of this 2 port network is given as G, then n 0 this is equal to N internal, which is being added by this device itself + gain of the device multiplied by whatever noise being delivered by this device at the left-hand side let us say that is given by n incident, so G into n i. Now from this n 0 how much power can be delivered to R a given resistor.

(Refer Slide Time: 12:27)



So let us model this whole source by an equivalent resistor R and an equivalent noise source which is given by e n, it is connected to a meshed load R from maximum power transfer theorem we know that maximum power from a source that can be delivered to a load only when this load resistance is equal to source resistance. So in that case if we calculate what is the maximum noise power delivered to the load, it is given by let us say noise voltage is en then the current component is e n by twice R, so I square multiplied by R, this is equal to e n if I put the value, this is 4 k T B R multiplied by 4 R square into R, so it comes k T B. So you see one interesting thing that maximum noise power, which can be delivered to a mesh load it is k T B, so it depends on Boltzmann's constant k, temperature of the device this is the noise temperature of the device and bandwidth, it does not depend on any resistor value so this is one important observation.

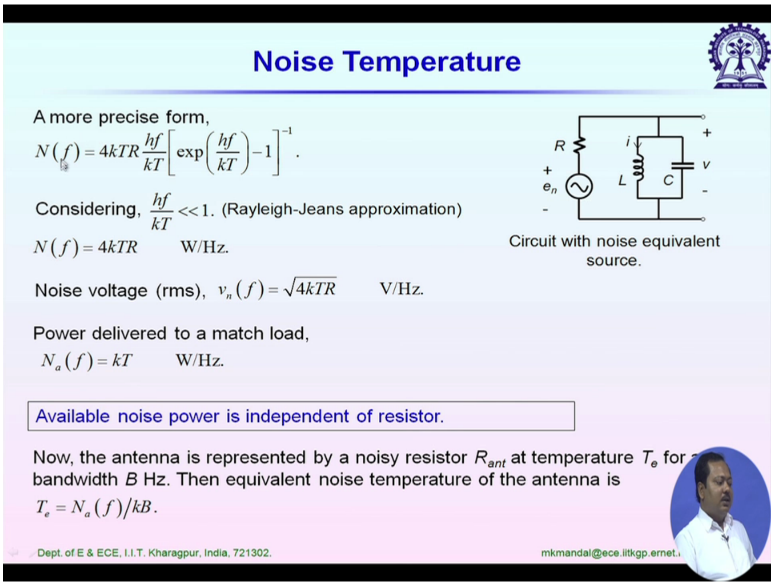
(Refer Slide Time: 13:51)



Now let us go back, let us say we have a resonator a tank circuit made of L and C, then noise power stored in one particular component inductor or capacitor it can be shown that it is half of the total available noise power, so total available noise power if I consider per unit hertz it is k T per hertz. The noise power stored in inductor, it will be k T by 2 similarly, it will be k T by 2 inside the capacitor we can also prove it here. Let us consider this circuit, it is connected to this noise source and which is represented by an ideal noiseless resistor R and the noise source e n, then now we calculate E c the average energy stored energy in the capacitor, this is half C v square, so we can calculate this half C v square as C by 2 integration 0 to infinity, then the transfer function square H (f) is the transfer function of the circuit into N (f) df.

So N (f) this is the noise power spectral density due to e n, because e n it is a function of frequency and we are considering N (f) as the one-sided power spectral density of this e n and h f, since L and C is given, we can calculate what is the transfer function, H (f) = simply 1 by 1 + j Omega R C + R by j Omega L, this is the system transfer function, then take magnitude square and put it in the equation then we calculate. Now we are considering the normalised value k T per unit hertz, but we have a finite bandwidth here. So what we can do, we can arbitrarily narrow down this transfer function around a mid-band frequency let us say f 0. So integration limit we will choose from f 0 - to f 0 + and we will consider the frequency bandwidth is very narrow so that this H (f) more or less is constant, so in that case you put the values here H(f) and N(f) is represented by constant value at N (f 0) and it comes out.

(Refer Slide Time: 17:23)

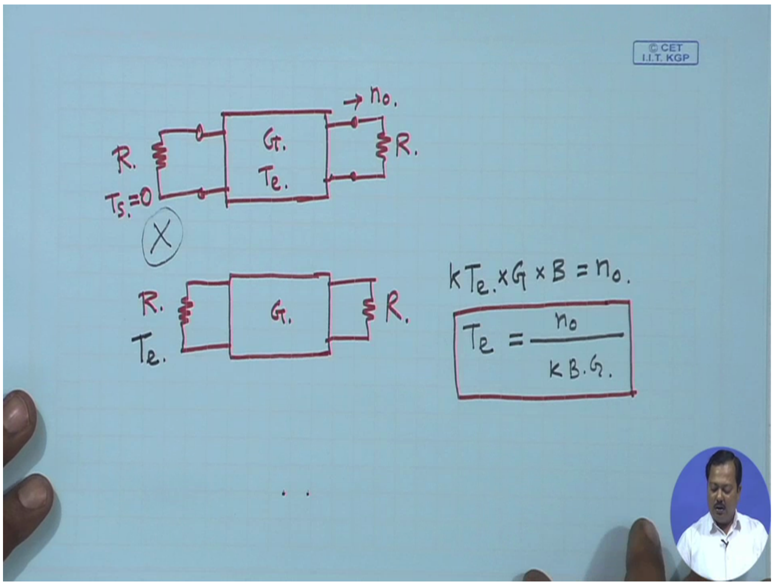


And if we put the values here and solve it, then it can be shown it is equal to N (f 0) by 8 R, so put the value of N (f 0), it comes k T by 2, so k T by 2 noise power is stored in capacitor similarly, another half is stored in inductor N (f) this is 4 k T R. So whenever we use the expression, noise power that is equal to 4 k T R, it is actually a simplified form. We have a more accurate form which is given here, N (f) noise power thermal noise power you remember that is equal to 4 k T R h f by k T, actually it is divided by this exponential function, it is shown here by to the power - 1, so exponential h f by k T - 1, this is the general form for thermal noise. And under a special condition when h f by k T is much less than 1, it is called Rayleigh-Jeans approximation and you see if I put h f by k T much less than 1 that means you are considering low-frequency high-temperature case.

So for lower millimetre wave frequencies we do not have any problem, we can use this approximation, but if we go to higher frequency let us say near to 300 gigahertz and go for space application, where temperature is negative, in that case we cannot use this, we have to use this whole form, but for indoor channel modelling or whatever we are doing on earth surface where we use room temperature 290 Kelvin, in most of the cases this formulation is valid below 100 gigahertz and we can write down then N (f) this is equal to 4 k T R watt per Hertz. Then the corresponding noise voltage RMS value, so already we discussed previously we used another parameter e n, so that is square root of 4 k T R volt per hertz then power delivered to a mesh load already we have seen this is equal to k T, it does not depend on R this is watt per hertz.

So available noise power is independent of any resistor, now let us say we have a receive antenna, so antenna it will generate some noise so whatever noise coming to antenna, it will be attenuated by the antenna loss. In addition to that antenna will add some extra thermal noise, so we can represent then antenna by an equivalent noise resistance, which can be given by R ant and let us say equivalent noise temperature is given by T e over a bandwidth B hertz. Then we define the equivalent noise temperature of the antenna as T e = N a by k B, so this is the definition of any equivalent noise temperature. So not just for antenna, we can also define this equivalent noise temperature of any amplifier also, so let us say the previous example or let me draw it again.

(Refer Slide Time: 20:44)

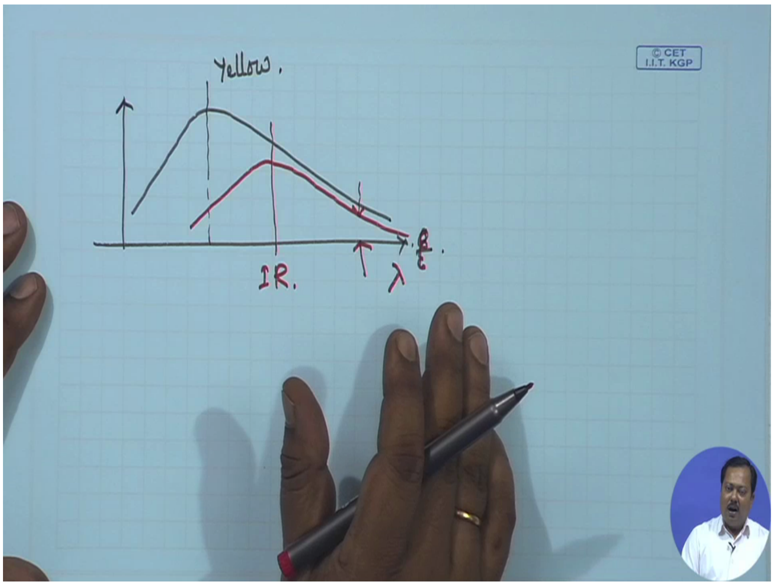


We have one amplifier, which is a 2 port network. At the input side I am representing the source resistance by R, which is at a temperature T s. Now amplifier amplification factor is given by G, then the effective noise temperature is given as T e. We have a mesh load here then noise power coming out from the amplifier is n 0. Now if I consider left-hand side, we do not have any noise source then whatever noise power absorbed in this mesh load it is due to the internal noise power generated inside this amplifier. So in that case that means we are considering T s = 0 and we do not have any noise contribution from left-hand side, so whatever noise we are having at the output side it is due to the amplifier only. Now, we are representing this amplifier by one noiseless amplifier G and the noise produced by the amplifier we are representing by a resistor equivalent register.

So in the antenna example we designated it by R ant, here since we are considering mesh scenario let us consider it as R. So in between these 2 R we have a noiseless amplifier and whatever noise actually coming from this practical amplifier we are representing by a noise source on left-hand side. Then the effective noise temperature it is given let us say by T e, then noise power this is equal to k T, so noise power generated by the left-hand side noisy source is k T E, it is passing through the amplifier so it will be multiplied by G and then if we consider a bandwidth of B we have to further multiply it by B and that is equal to the output noise n 0. So effective noise temperature of this amplifier T e, we can write down this is equal to noise power at the output divided by this is k B into G.

And if I consider per unit hertz we have to just put B = 1, so this represents the effective noise temperature of this amplifier. Similarly, we can do it for any lossy device also in general. Now we already have seen what is the effect of noise for any 2-port network or for any antenna, now receive antenna it can collect also blackbody radiation, so what is blackbody radiation let me first discuss it. So let us consider earth surface or any object, it can be human body it can be any home furniture, any building, anything. Now from Black Plank's law we know that it will continuously radiate and that radiation it is a function of temperature and frequency.

(Refer Slide Time: 25:08)



So if I plot radiation intensity coming from any blackbody, it varies with frequency f and we are plotting the radiation intensity or sometimes we call simply radiance L, so this peak value it depends on the temperature of that object. For example, some its temperature is approximately 6500 Kelvin and for which this peak value is at optical frequency yellow line. Now if I consider Brown earth surface and temperature let us say 300 Kelvin, then in that case this peak value it corresponds to infrared frequency range IR range. And if we go further down sorry this is not versus frequency, this is versus wavelength. So if we go further down that means if we decrease the frequency further, so we have this spectral component it decreases, but it is not negligibly small at millimetre wave frequencies. Now, if we have any antenna let us say it is focusing towards Earth from satellite then it will collect this radiation, which is coming out from Earth surface and we have a degrading effect on the antenna performance.

Similarly, any Earth Station antenna it can point towards sky and it can pick up the radiation due to Sun, it can pick up radiation due to atmosphere, atmosphere also as secondary radiation dwelling radiation and also it can pick up radiation from other galactic sources and all these are sources of noise. This noise is superimposed with the signal power and it will degrade SNR of the antenna and receiver system as a whole. So next day we will see that the brightness or this black body radiation how it affects any SNR or the receiver performance and then we will combine the noise figure contribution of all other components in the receiver chain and combining this all the effect due to the blackbody radiation and noise contribution of the receiver chain, as a whole we will calculate the SNR of the receiver. Okay, so let us finish here thank you.