Remote Sensing: Principles and Applications
Prof. R. Eswar
Department of Civil Engineering and Interdisciplinary
Program in Climate Studies
Indian Institute of Technology-Bombay

Lecture-40
Passive Microwave Remote Sensing-Part 1

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. In this lecture we are going to start a new topic known as passive microwave remote sensing or also known as passive microwave radiometry. We know earth emits radiation because of its internal energy or it is own temperature and that was the major physical reason behind us doing thermal infrared remote sensing.

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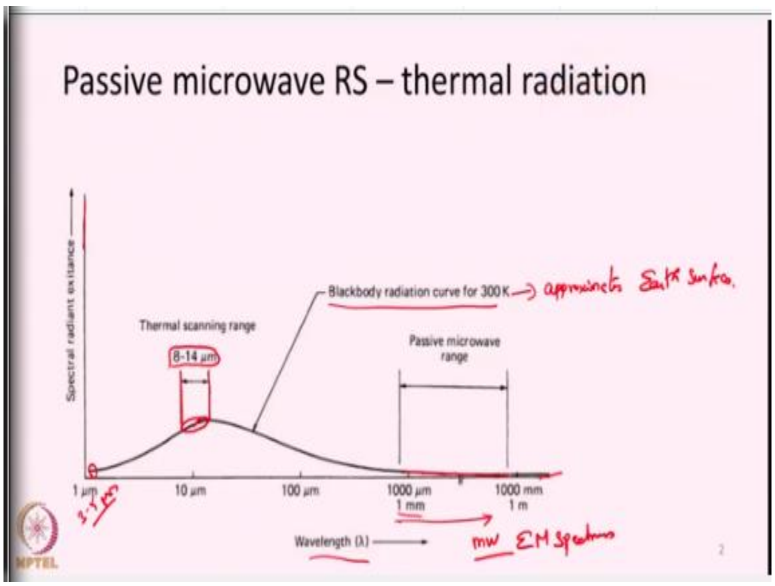

Say here we have wavelength in x-axis with the spectral radiant emittance or the radiant flux density in the y axis and the curve is plotted for a black body at 300 Kelvin. So, this basically approximates earth surface. If you look at this curve the radiation will be starting around 1 µm and will start emanating around 3 to 5 µm range and then there will be a long tail. In thermal infrared remote sensing, we use the wavelength range of 8 to 14 µm, we send satellite sensors in this particular range, observe the radiance and calculate the temperature of earth surface features. But this curve will not stop abruptly, earth surface will be keep on emitting radiation and it will have like a long tail which is extending all the way up to the microwave portion of the electromagnetic spectrum. So, here even if you observe in millimeter range or cm range, there are small amount of radiation that is constantly being emitted by earth surface. So, this radiation is what we are going to make use of in passive microwave radiometry.

That is starting from short wave infrared or mid wave infrared portion, the 3 to 5 μm range earth will be keep on radiating energy. This radiation was slowly increased and it will reach a peak in the long wave infrared portion around this 9.5, 9 to 10 μm range. There if we sense, we call it as thermal infrared remote sensing, but this radiation will not abruptly stop from earth surface. Earth surface will be emitting energy even in microwave wavelengths. That is with wavelengths in the order of centimeters maybe from 1 cm to 100 cm. If we observe this radiation from earth surface and use it for different applications, we call that as passive microwave remote sensing or passive microwave radiometry.

So, naturally this is an extension of thermal infrared remote sensing. Extension means, we are not producing any new form of energy, whatever the earth itself is emitting we are observing it but in a different wavelength**.** So, we are not observing anymore in 8 to 14 μm wavelength but we are observing earth emitted energy in microwave with the wavelengths in order of centimeters. In those wavelengths also, solar radiation is not going to play any role, because we have already seen. Once we cross this 5 μm wavelength solar radiation reaching the earth surface almost goes to zero, so we can safely neglect any incoming solar radiation. So, whether during day time or night time whatever radiation we observe in microwave wavelengths essentially that energy will be due to emission from earth surface.

Just study this in parallel with thermal remote sensing, even in the 8 to 14 μm wavelength whatever we observe is basically due to emissions from earth surface. Same concept is applied here, we are observing at a different wavelength but still whatever we are observing is due to earth surface own emission. So, our wavelength only changed, but the source is earth surface and the various features present on the earth surface.

So, what exactly is the microwave portion of electromagnetic spectrum? This also we have discussed in the introductory classes. So, in general the microwave portion of electromagnetic spectrum that we use for remote sensing of earth surface spans between the wavelength range of around 1 cm to 1 meter.

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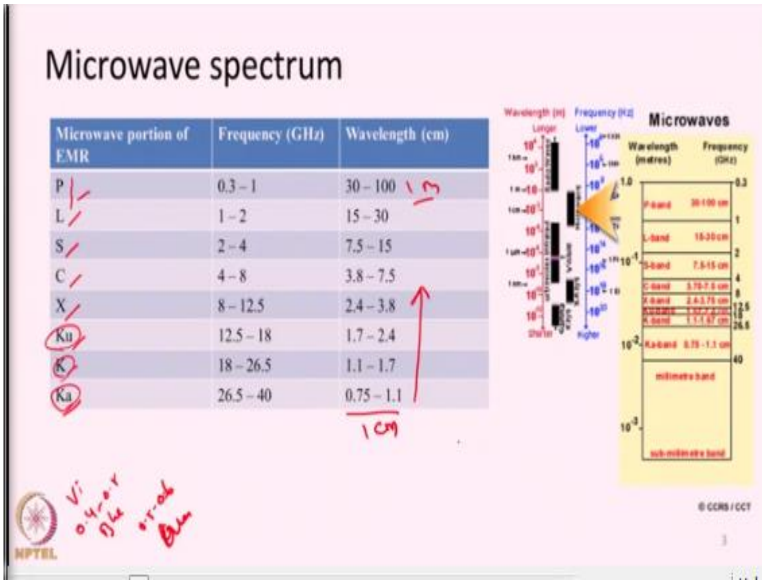

So, we can classify it as Ka band, K band, Ku band, X, C, S, L and P in the range of increasing wavelength starting from 1 cm wavelength to 1 meter wavelength. We have lot of divisions in between. For our own understanding, this nomenclature P, L, S, C, X have been developed in olden days as a secret codes during military applications.

One of the earliest applications of microwave is military and defense surveillance needs. So, the random names were given for frequencies in order to keep it secretly, and that name prevailed even now. So, these are all the common names we give to the different portion of microwave portions. Microwave portion is a pretty long portion of electromagnetic spectrum, we have divide it into certain classes and use for remote sensing. Whatever the portion from K band to P band, it is not essentially the full microwave portion of spectrum. Microwave is still really a very huge part of electromagnetic spectrum and it has its applications in various domains. In communications, our cell phones, everything depends on microwave based communications, microwave oven transmits microwaves for cooking of food. So, microwave is there everywhere around us and we use it for several applications, remote sensing is just one of the applications in which microwave wavelength of EMR is being used.

Just imagine we have some transmitter kind of thing emitting energy in one particular microwave frequency, there is a passive microwave sensor which observes the surface in the same frequency. Just think what will happen? Whatever this transmitter is radiating is going to reach the satellite sensor and the satellite sensor is going to think something is coming from the earth surface. And as a end user when we take that image we will see and think what is there on the surface, we will not know that there is some transmitter which is radiating energy, it maybe a cell phone tower. So in order to avoid such confusions the microwave spectrum has been divided and for each application, each portion of the spectrum has been allotted.

Similarly for remote sensing, a certain frequencies has been allotted, only this frequencies has to be used for microwave remote sensing. And only this frequency has to be used for communication purposes. If these frequencies clash, say if a communication agency is using a particular frequency allotted for remote sensing if they have a microwave transmitter then that is going to interfere with what the satellite is going to observe. Then there is some artificial source that is emitting energy that is going to cause interference in satellite observations; we call this as RFI radio frequency interference. These sort of things tend to happen but in order to minimize this or avoid this, the microwave portion has been split up and several small portions has been created and each application has been allotted certain bands.

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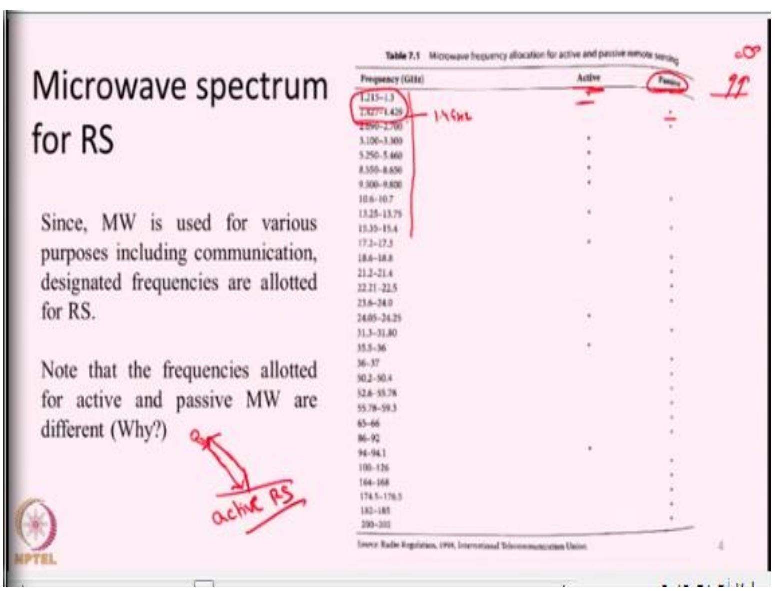

Say for remote sensing purposes, these are some of the frequencies which we can use for earth observation or observation of atmosphere. We can see here there are 2 titles active and passive, what exactly active and passive means? Passive is the passive microwave remote sensing that we have just got introduced to or what we are discussing right now. That is whatever we are observing from space the energy is primarily due to earth's own emission. There is also an active mode of remote sensing, what exactly active mode of remote sensing or active microwave remote sensing is, we will have a sensor known as radar, this will transmit some electromagnetic radiation with a given frequency. This will interact with earth surface features and will be reflected back. This will again reach the sensor, and the sensor will observe it and use it for imaging purposes. So, this process where the sensor itself will transmit certain energy and receives it back, we call it as active mode of remote sensing, active remote sensing.

So, in microwave it is possible to do active remote sensing. We can send a radar to space that will transmit EMR in microwave wavelength and get the reflected signals back. So, active remote sensing is a topic that we are going to see next after we finish passive microwave. So, even in microwave spectrum for active and passive the frequencies have been divided. For example let us take L band frequencies, say 1.2 to 1.4 range gigahertz frequency. If you want to do active remote sensing, you are supposed to use this 1.2 to 1.3 gigahertz, if you want to do passive remote sensing in L band you have to choose this 1.4 gigahertz frequency, there should not be any mix, why? If an active remote sensing sensor and a passive remote sensing sensor work in same frequency then the active radar itself will become like an interference to the passive sensor.

Let us see, there is a satellite called SMAP soil moisture active passive which is launched by NASA. So, it has both a passive microwave radiometer and also a radar. Both will work in L band. But the frequency in which the sensor will send signals is different from the frequency in which the radiometer will observe. So, the radar will send in a different frequency and will observe in a different frequency, say if it transmits around 1.3 gigahertz then receives the signal back in 1.3 gigahertz, whereas this passive microwave radiometer will not transmit anything but will observe frequency only in 1.4 gigahertz. So, even within a same satellite, if you have active and passive mode of remote sensing together, the frequencies will be different. Because the active radar should not act as an interference to the passive, imagine the active is also transmitting energy at 1.4

gigahertz, what will happen? 1.4 gigahertz will go get reflected from a surface, will come back and passive micro radiometer will observe it, thinking that it is coming only because of earth's emission, that itself is an interference. So, in order to avoid this interference there has been specific channels created to make sure or to minimize this radio frequency interference. So, for passive microwave remote sensing there are like specified channels or specified bands in which observations will be made.

Before moving on to the concepts of passing microwave radiometry, we will look at the Planck's law one more time. Planck's law we have seen several times in the introductory classes as well as in thermal infrared remote sensing. Here in passive microwave radiometry also Planck’s law plays a major role, because the radiation coming out of earth surface is thermal in nature.

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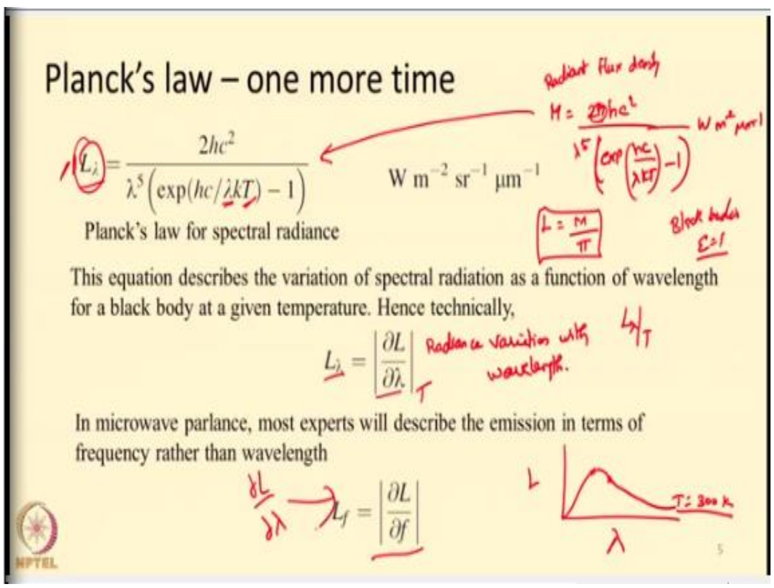

The original form of Planck's law that is for the radiant flux density is given by

$$L_\lambda = \frac{2\pi hc^2}{\lambda^5\left[exp\left(\frac{hc}{\lambda kT}\right)-1\right]}$$

So this is the original form of Planck's law that we have seen earlier. The units of radiant flux density is W/m^2/µm. So, for isotropic radiators of Lambertian surfaces we have seen that radiance is equal to (radiant flux density)/π.

So, by using this particular relationship we have derived this equation for radiance. So, this is the Planck's law for radiance, the only difference is this term π will not be there, this also we have seen earlier. This particular equation will give us the radiance coming out of a black body, so essentially these equations are defined for black bodies whose emissivity is equal to 1 always in all the wavelengths. So, if you look here, there are like 2 independent variables, T can vary independently and λ can vary independently. If we assume the black body is at one particular temperature then T will become a constant and λ will be the variable. And hence this equation L_λ will tell us how radiance vary with wavelength. We can draw a curve for T = 300 Kelvin and say if we fix the temperature of an object, the equation given here will tell us at which wavelength what will be the radiance.

So, mathematically this can be written as a partial derivative, that is this L_λ is nothing but the variation of radiance with respect to wavelength $\frac{\partial L}{\partial \lambda}$ at a temperature T. So, here we are holding temperature as a constant that is why this partial derivative is coming with respect to λ.

In microwave parlance, whenever we enter the microwave domain of remote sensing most of the people like the engineers who develops the microwave antenna, the sensor system and everything, they prefer dealing in terms of frequencies. But as remote sensing people we prefer talking in terms of wavelength. So, essential there is always need to convert between expressing in terms of wavelength and expressing in terms of frequency.

So, it will be easy for us, if we can convert this Planck's equation to express in terms of frequency. The variation of radiance for an object at a given temperature T with different frequencies that is rather than having λ in x axis, now we are going to put frequency in the x axis. We have to convert this $\frac{\partial L}{\partial \lambda}$ into $\frac{\partial L}{\partial f}$, where f is the frequency.

It may seem to be a very straight forward operation, just by replacing λ with ν, we know the relationship C = νλ, using it we can replace. But it is not as straight forward, it is not a mere substitution of λ with frequency. It needs a small mathematical operation in between, so we will see how to do it? So, once we do it, we will be in a position to calculate the radiance with a given frequency.

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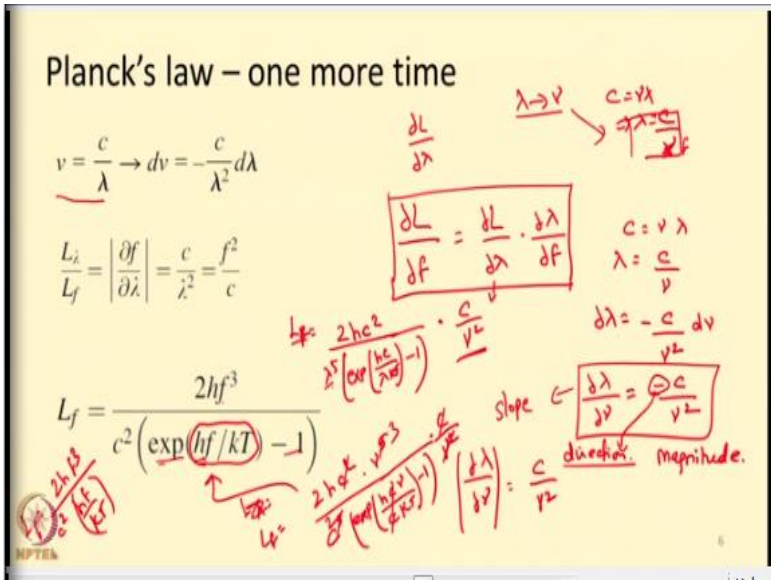

Just examine the equation once more. The radiance equation is a function of λ and we can write λ as a function of ν, λ = C/ν, so λ varies with frequency where C is a constant. So, essentially we need $\frac{\partial L}{\partial f}$ or $\frac{\partial L}{\partial \nu}$, but what we have in our hand is $\frac{\partial L}{\partial \lambda}$. So, essentially if we use the chain rule of partial differentiation, we can write it as ∂L/∂f = (∂L/∂λ) × (∂λ/∂f). So, if we do this we will be in a position to calculate what will be the change in radiance with respect to frequency**.** So, ∂L/∂λ we already have in our hand, that is the Planck's equation given in the previous slide. So, this equation is nothing but the ∂L/∂λ. So, now we have to calculate ∂λ/∂f, that is the variation of λ with respect to frequency, so C = νλ or λ = C/ν. Just differentiate it once ∂λ = **-** C/ν^2 ∂ν, so I am interchangeably using ν and f to represent frequency. So, ∂λ/∂ν = **-** C/ν^2**.**

So, this is actually a negative equation where the negative sign represents the direction in which λ changes with change in frequency. That is as frequency increases λ will decrease and vice versa. So, this negative is an indication of direction, so derivative is nothing but mathematically it is a slope**,** so normally we attach the concept of derivative with slope, so in which direction this variable will change. So, as we increase frequency, λ will decrease and vice versa. For our particular application the direction is not important but what we need is the magnitude. So, magnitude means I am just going to take the modulus of this particular function which means C/ν^2, the minus sign will go off. So, here we are going to calculate the variation of wavelength with respect to frequency. So, when we differentiate λ with respect to frequency we get minus C/v^2 where minus sign indicates the direction in which λ will change. So, we are taking modulus in order to avoid direction, we are not interested in seeing in which direction the slope is going to go. So, we are taking modulus of it and we are getting a C/v^2, so substitute everything in planck's equation. Now we have to replace all the λ with respect to ν with relationship we found out between λ and ν. Now rather than writing L_λ, we will use L_f. So, this is the way in which we have to derive the Planck's equation to be expressed in terms of frequency.

So, it is not a straightforward substitution for λ and convert it into frequency, we have to use the partial chain rule and derive this particular equation. So, this is nothing but the simple Planck's rule expressed in terms of frequency. So, now rather than telling you what is the radiance coming out of an object at a temperature of 300 Kelvin at 1.4 gigahertz, we can directly find it; we need not convert frequency to wavelength and then substitute it. So, directly we can use and get the variation of radiance at a given frequency for an object at a temperature T**.**

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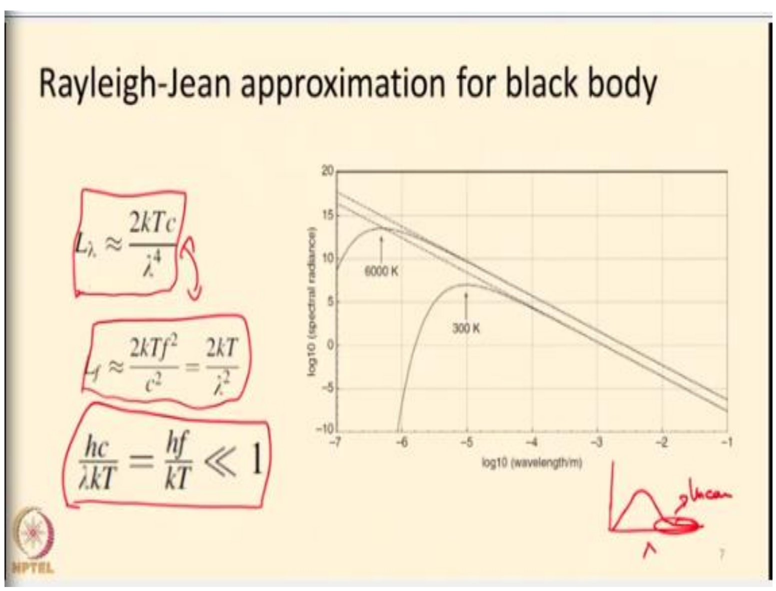

Now what we have seen till now is a generic form of Planck's equation, the original form without doing any modification. In microwave wavelengths especially in the longer wavelengths, the Planck's curve will be like a linear line.

We will see the tail portion approximated to be linear; it need not be treated perfectly as the exponential curve. So, this approximation is known as Rayleigh-Jean approximation for black bodies, Rayleigh Jean approximation of Planck's law to be more specific.

The Rayleigh Jean approximation says that if hf/kT is less than 1 or $hc/\lambda kT$ is much less than 1, then in this particular equation we can drop the exponential function and simply write it as $L_f = (2hf^3)/C^2$. So, if we do this, then the frequency with respect to wavelength gets modified. So, these 2 simplifications of the Planck's law is what is known as Rayleigh Jean approximation. From Rayleigh Jean approximation what we can observe is the relationship between temperatures of an object under radiance coming out becomes linear, that is L_λ becomes $2\ kTC/\lambda^4$. So, the T is in a linear relationship with respect to radiance. And also all the computations becomes highly simplified, we need not take the exponential. The many number of a computation steps you need to calculate to perform the certain operations is much simplified, the equation is very simple. So, Rayleigh-Jean approximation first tells us the Planck's curve or the radiation that is emitted by a black body becomes linear towards the end, that is one thing. And second thing is all the computations, that we are going to do becomes much simpler.

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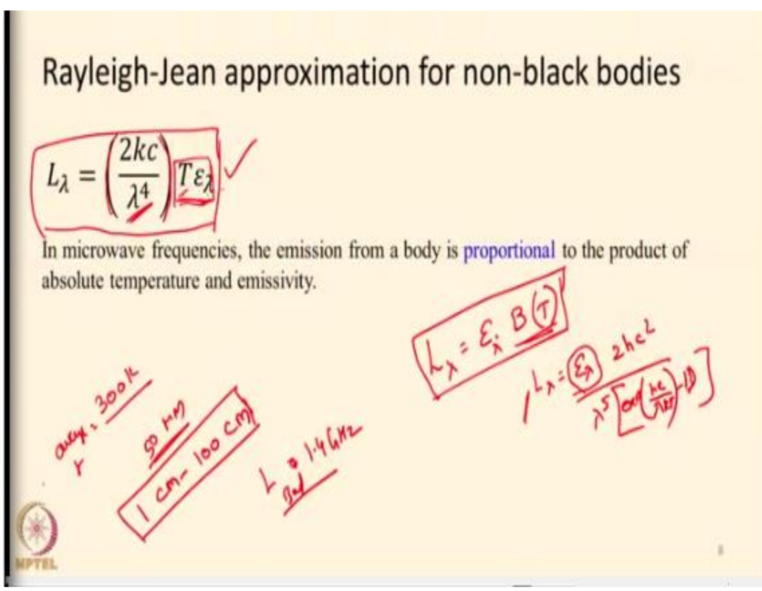

Till now we have seen the Planck's equation for black bodies. Even when we converted into frequency or even when we did the Rayleigh Jean approximation, everything was for a black body. But we know most of the earth surface features are non-black bodies, they will have emissivity less than 1 and the emissivity will also vary with wavelength. So, for such non-black bodies, the radiance will be given by emissivity times the Planck's law of the object at a given temperature T. So, what we did it in thermal infrared remote sensing same thing we will do here, even in this particular wavelength we will multiply the Planck's equation with spectral emissivity. However here we will use the Rayleigh Jean approximation, because in microwave wavelengths especially for features of earth surface when the object is at 300 Kelvin temperature, Rayleigh Jean approximation will hold good roughly when the wavelength once crosses 50 μm.

Let us say a sensor is being sent to space. It is going to operate in L band around 1.4 gigahertz**.** So, hence as soon as the sensor is designed and sent to space, wavelength is also fixed. It is going to observe only in this 1.4 gigahertz frequency or roughly 24 centimeters wavelength, so now this entire term within the bracket becomes a constant for that particular sensor. So, the radiance coming out of any non-black bodies is now directly proportional to the product of temperature of the object and its surface spectral emissivity. So, this signifies for non black bodies the radiance emitted is directly proportional to the product of temperature and spectral emissivity. So, here both temperature and emissivity has equal say in defining what will be the radiance that is coming out of an object.

So, if you look at the equation for radiance in TIR band, this is highly non-linear, emissivity is here and the temperature is here in the denominator within the exponential all these things. But if you look at after the Rayleigh Jean approximation, equation becomes much simpler and the radiance is directly proportion to the product of temperature and emissivity. So, here the weightage of temperature and emissivity is equal in defining the radiance, both have equal say. If temperature increases radiance increases to the same extent, if emissivity increases radiance increases to the same extent and vice versa. So, here the influence of emissivity and temperature both are equal in defining the radiance coming out whereas in TIR wavelength in the original form of Planck's law, the change in temperature will have a more influence or a larger say in defining what will be the radiance coming out of an object. Here also one thing we have to remember, the product of temperature and emissivity for any given object is commonly referred as brightness temperature in microwave parlance.

When we define brightness temperature in TIR remote sensing we defined it as, the temperature of black body we have in order to produce the same radiance as observed by the sensor. Sometimes in most of the literature you can see brightness temperature is defined as the product of temperature and emissivity. Because in microwave wavelength, people assume atmospheric effects are negligible and hence whatever is observed by the sensor is almost effectively free of atmospheric effects. And if you remove this sensor response function whatever the radiance received by the sensor is just due to the mere effect of temperature and emissivity. In microwave parlance, the word brightness temperature in several literatures will refer to the product of temperature of an object and emissivity of the object.

So as a summary, in this particular lecture we have discussed or we have got introduced to the concept of passive microwave radiometry. We have seen what are all the spectral bands used in passive microwave radiometry. And also we have seen in detail about the conversion of Planck's law from with respect to wavelength to with respect to frequency also we have seen the Rayleigh Jean approximation. The Rayleigh Jean approximation will help us to simplify our calculations and also to understand the relationship between temperature and radiance and also emissivity and radiance. With this we end this particular lecture.

Thank you very much.